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SOAC: STATE-OF-THE-ART CAR ENGINEERING TESTS AT DEPARTMENT OF TRANSPORTATION HIGH SPEED GROUND TEST CENTER. FINAL TEST REPORT. VOLUME VI. SOAC INSTRUMENTATION SYSTEM

Boeing Vertol Company

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Urban Mass Transportation Administration
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16. Abstract

This six-volume report presents the technical methodology, data samples, and results of tests conducted on the SOAC on the Rail Transit Test Track at the High Speed Ground Test Center in Pueblo, Colorado during the period April to July 1973. The UMTA-sponsored Urban Rail Supporting Technology Program, for which TSC is Systems Manager, emphasizes three major development task areas: facilities, technology and test program. Test program development comprises three sub-areas: vehicle testing, ways and structures testing and track geometry measurement. The objective of the SOAC program is to demonstrate the current state-of-the-art in rail rapid transit vehicle technology, with passenger convenience and operating efficiency as primary goals. The objectives of the Engineering Test program are to provide a set of SOAC engineering data and to further develop the methodology for providing transit vehicle comparisons. These objectives were met with the presentation of the test results in this report and the incorporation of refinement to the testing methodology into the General Vehicle Test Plan, GSP-064. In this series, Vol. I contains a description of the SOAC test program and vehicle, and a summary of the test results; Vol. II, Performance Test data; Vol. III, Ride Quality Test data; Vol. IV, Noise Test data; Vol. V, Structural, Voltage, and Radio Frequency Interference Test data and Vol. VI a description of the Instrumentation System used for performance, ride quality and structural testing.

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PREFACE

This test report, presenting the results of engineering tests on the State-of-the-Art Cars (SOAC), derives from the efforts of two agencies of the U.S. Department of Transportation: the Rail Programs Branch of the Urban Mass Transportation Administration's Office of Research and Development and the Transportation Systems Center.

The report is presented in six volumes. Volume I is a description of the program and a summary of the test results. Volumes II through V are organized to technical disciplines as follows: Volume II, Performance; Volume III, Ride Quality; Volume IV, Noise; and Volume V, Structures, Voltage, and Radio Frequency Interference. This volume, Volume VI, contains a description of the SOAC Instrumentation System used for Performance, Ride Quality, and Structural Testing.

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Section 1

GENERAL DESCRIPTION AND CONCEPT

The purpose of the instrumentation system for the State-of-the-Art-Car (SOAC) is to measure and record the operating characteristics of the vehicle. These characteristics have been grouped into three catagories, Ride Quality, Structural Behavior, and Performance. Ride Quality denotes those attributes which affect the comfort or well-being of the passengers, and includes various components of linear and angular acceleration. Structural Behavior includes the stresses in various members of the vehicle and the relative motions of the truck with respect to the vehicle frame. Performance relates to the speed, acceleration and braking characteristics of the car and the electrical power required to operate the vehicle.

A block diagram of the system is shown in Figure 1-1. The measured parameters are grouped according to the preceding three operational catagories, and include linear and angular accelerations, relative motions, strains, temperatures, voltage, current, electrical power, and wheel speeds. These quantities are measured by appropriate transducers mounted on various parts of the vehicle. Electrical signals from these transducers are conducted by cables to an interface panel which is connected to an instrumentation console. The console contains two magnetic tape recorders, two light beam oscillographs, a time code generator, a temperature recorder, and the signal conditioning required to power the transducers and convert their signals to a level compatible with the magnetic tape recorders. Equipment temperatures are measured by thermocouples and are recorded directly by the temperature recorder. The other transducer cables are connected to their respective signal conditioning units.

The outputs of the signal conditioning units can be selectively recorded on the two tape recorders and the oscillographs. Any twenty-eight selected parameters can be recorded on tape. These same parameters can also be recorded on the oscillographs. In addition, signals corresponding to the four wheel speeds are recorded directly on the oscillographs. Total power consumption is recorded on tape and displayed on a mechanical counter. The time code generator provides signals

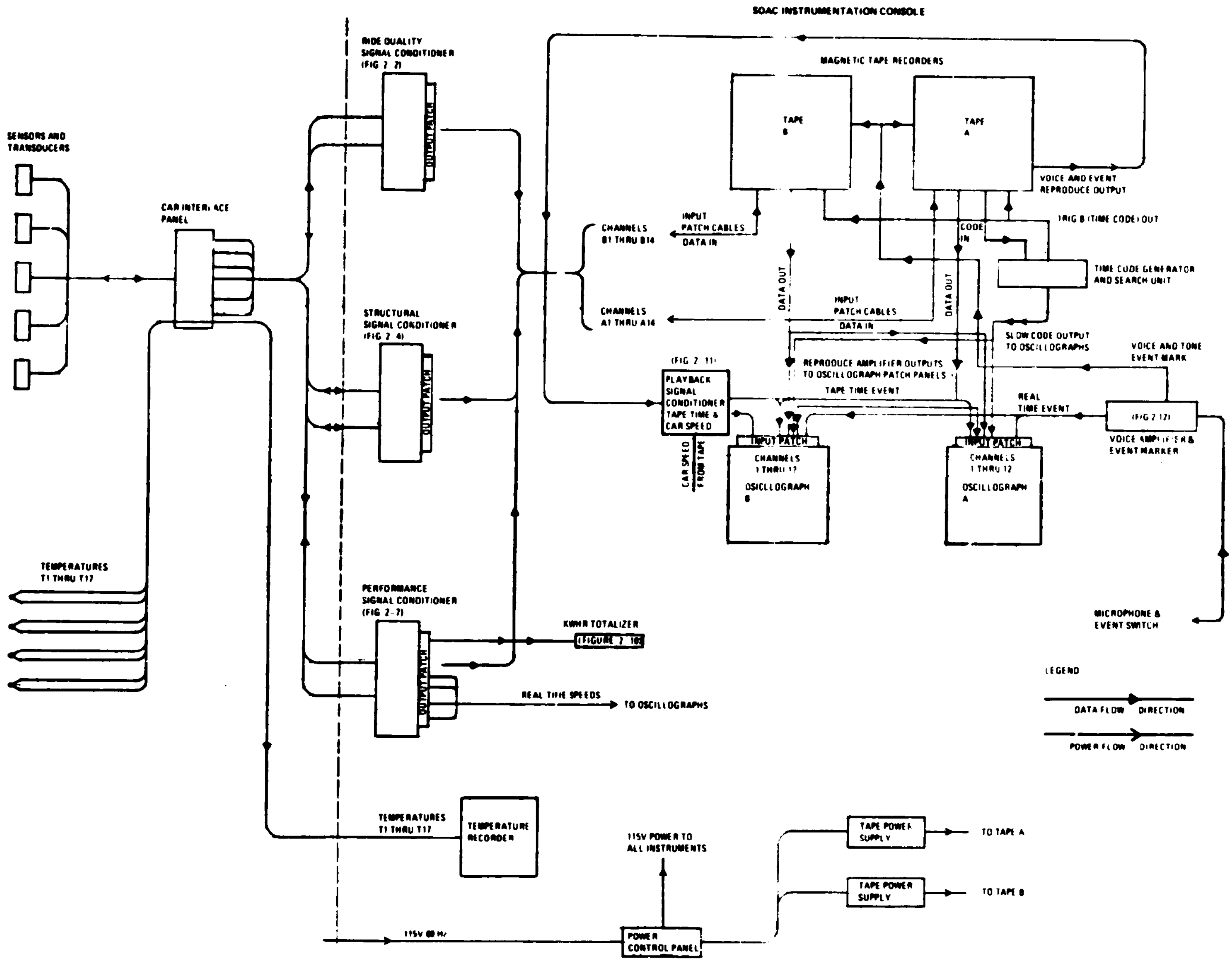


Figure 1–1. SOAC Instrumentation System Block Diagram

that are recorded on tape and on the oscillograph traces for facilitating subsequent analysis of test data.

The test recording scheme is based on conducting separate tests for Ride Quality, Structural Behavior, and overall vehicle Performance. Not enough recording channels are provided to record simultaneously all conditioned transducer outputs. The recording system has been designed to achieve flexibility, operational convenience, and trouble-free operation.

An important feature of the system is that all of the signal conditioning and recording equipment can be removed from the vehicle when not needed. The transducers are permanently mounted and are connected electrically to an interface panel located in a junction box mounted beneath the floor. Connection to the signal conditioning and recording equipment is made by removing a cover plate which forms part of the floor of the car, and connecting cables to the interface panel. When the car is used for demonstration runs, the instrumentation console is disconnected and removed from the car. The cover plate serves to protect and conceal the instrumentation interface panel during demonstration runs.

Section 2

DESCRIPTION OF SYSTEM

2.1 MAIN COMPONENTS AND SIGNAL FLOW

The main components of the instrumentation system are illustrated in the block diagram in Figure 1-1. The physical parameters to be measured are sensed and converted to low-level electrical signals by transducers mounted on the vehicle. Electric cables connect the transducers, which are mounted on the exterior of the vehicle, to a car interface panel. This panel is mounted just beneath the floor of the vehicle and is covered and concealed by a plate when the instrumentation system is not in use. Electrical power to the system is supplied through a power panel.

All measured parameters are brought into the car through the car interface connector panel. The thermocouples go directly to the Leeds and Northrup temperature recorder, while all other parameters are channeled to their respective signal conditioning units. The outputs of the signal conditioning units are terminated on miniature patch panels on the rear of each conditioning unit. All parameters are buffered, and their outputs are single-ended with output impedances of less than 100 ohms.

The tape recorder inputs are patched into the conditioner output jacks to record the desired parameters (up to fourteen channels per recorder, twenty-eight total). All outputs from the tape recorder reproduce head are standardized at one volt full scale. The signals are routed through resistive dividers and shunt resistors mounted on the side of the oscillographs, and then to the light beam galvanometers.

All measured parameters follow this route with the exception of wheel speeds and total power consumption. The four wheel speeds have analog outputs recorded directly on the oscillograph. In addition there are pulse outputs which can be displayed on a counter or recorded on tape. Total power consumption is recorded on tape as a series of pulses, each corresponding to one hundred watt-hours. There is also an output that will drive a twenty-four volt impulse counter, one step per hundred watt-hours.

Synchronization of data and test events is accomplished by means of an IRIG B time code generator, event marks recorded on tape and oscillographs, and by voice commentary recorded simultaneously on both tape recorder voice channels.

The event marker is put on the oscillograph traces as a one-second dc level shift, and on the tape recorders as a one-second tone burst (1 kHz) superimposed on the voice channels. The duration of the event mark (one second) is independent of length of time the event marker button is pushed.

There is a finite time between a signal being recorded on magnetic tape and playback into the oscillographs. This time delay is due to the recording speed and the physical distance between the recording and playback heads of the tape recorders. The event marks and the four wheel speeds are recorded directly on the oscillographs without the intermediate steps of recording on tape and playback. Hence, these signals will lead the other parameters on the oscillographs traces by the transport time of the tape between the recording and playback heads.

The tape transport delay time introduces an apparent time difference between those parameters recorded directly on the oscilographs and those recorded on tape and played back for recording on the oscillographs. Correction of this apparent time difference is provided by a second event mark for the oscillographs which is delayed with respect to the directly recorded event mark by the tape transport time. This delayed event mark is generated by a tone decoder which receives the voice channel from one tape recorder.

In addition to the IRIG B output to the magnetic tape recorders, the time code generator has slow code outputs to put time of day on the oscillograph recorders. The transport of tape recorder A (mounted in the left hand side of the console) is connected to the time code generator search unit. This arrangement permits automatic tape search for a particular time or run number.

As noted previously, the four wheel speeds are recorded as frequencies on tape. One speed channel can be obtained from the tape playback head, conditioned, and recorded in analog form on an oscillograph. This speed signal will be delayed relative to the four directly recorded oscillograph speed signals by the tape transport delay time.

The electronic modules for decoding the event tone recorded on the voice channel and for converting the speed frequency signal to an analog signal are contained in the playback signal conditioner mounted in the rear of the console. As discussed previously, both of these signals are recorded on the oscillographs. The playback signal conditioner is also used during data reduction to retrive event marks and speed analog signals from the magnetic tape.

As previously noted, the four wheel speeds are recorded directly on the oscillographs as analog signals. These signals are generated by four frequency to direct current (F/DC) convertors located in the Performance Signal Conditioning panel.

2.2 SIGNAL CONDITIONERS: GENERAL DESCRIPTION AND THEORY OF OPERATION

The three Signal Conditioning Panels (Ride Quality, Structural and Performance) provide power for the various transducers and amplifiers within each panel. The standard output level of signals for recording in analog form is minus five volts to plus five volts. Speed and electrical power consumption are recorded as pulses. Zero offset and gain control are provided for all analog parameters to condition them to the standard span.

The input signals and transducer excitation voltages are carried by seventy-five pin connectors. Each signal conditioner has two of these connectors. The six connectors are shown in Figure 1-1. Each connector can accommodate twelve parameters, with six pins assigned to each parameter. The remaining three pins are used as a monitor chain. The six pins assigned to each parameter include three for excitation power (plus, minus and common), two for the signal, and one for the shield. Table 2-1 shows the pin connection scheme for each of the six connectors.

TABLE 2-1. INPUT CONNECTOR CONFIGURATION

Parameter No.	Plus Power	Common	Minus Power	Signal	Shield
1	1	2	3	4,5	7
2	8	10	11	12,13	14
3	15	16	17	18,20	21
4	22	23	24	25,26	27
5	28	29	30	31,32	33
6	34	35	36	37,38	39
7	40	41	42	43,44	45
8	46	47	48	49,50	51
9	52	53	54	55,56	57
10	58	59	60	62,63	64
11	65	66	67	70,71	72
12	73	74	75	76,77	78

Power for the "System Ready" lamps is routed through the input cables down to the car interface connector panel. The monitor chain (pins 79, 80 and 82) insures the input cables are connected before a test.

The "System Ready" lamps on each Conditioner Panel also monitor all of the power supplies in each signal conditioner. If any supply should fail, the "System Ready" light emitting diodes (LED) will not light.

The SOAC Calibrator, shown in Figure 2-1 is powered by the conditioner. The calibration signals are fed back on the signal input pins. A more detailed description of the Calibrator will be found in Section 3.1.1.

The output of each channel of each signal conditioning panel appears on a patch panel, located on the back of the signal conditioning panel. Each channel is identified by a number; this number appears adjacent to the output termination for that channel on the patch panel and also on the corresponding circuit card within the signal conditioner. The parameters to be recorded are selected by plugging tape recorder input cables into the appropriate patch panel terminations.

2.2.1 Ride Quality Signal Conditioner: Description and Theory of Operation

The Ride Quality Signal Conditioner accepts signals from twenty-two linear servo accelerometers mounted on the vehicle. These signals are amplified and buffered as required for recording on tape. The wiring diagram on the unit is shown in Figure 2-2. The unit consists of twenty-two identical amplifiers (see Figure 2-3 for the amplifier circuit) and a common DC power source, which supplies +15 volts, -15 volts, and common to the accelerometers.

Each accelerometer contains its own amplifier. The amplifier in the Ride Quality Signal Conditioning panel provides a range of voltage gain adjustment from one to four, zero and offset adjustment, and change of impedance level for the corresponding accelerometer signal. This amplifer has a high input impedance and an output impedance of less than 100 ohms. Output signals can be conditioned by the gain and offset adjustments to cover the standard span of -5 to +5 volts.

2.2.2 Structural Behavior Signal Conditioner: Description and Theory of Operation

This panel contains fourteen channels of resistance transducer signal conditioning and ten channels of full-bridge strain gage conditioning. The wiring diagram is shown in Figure 2-4.

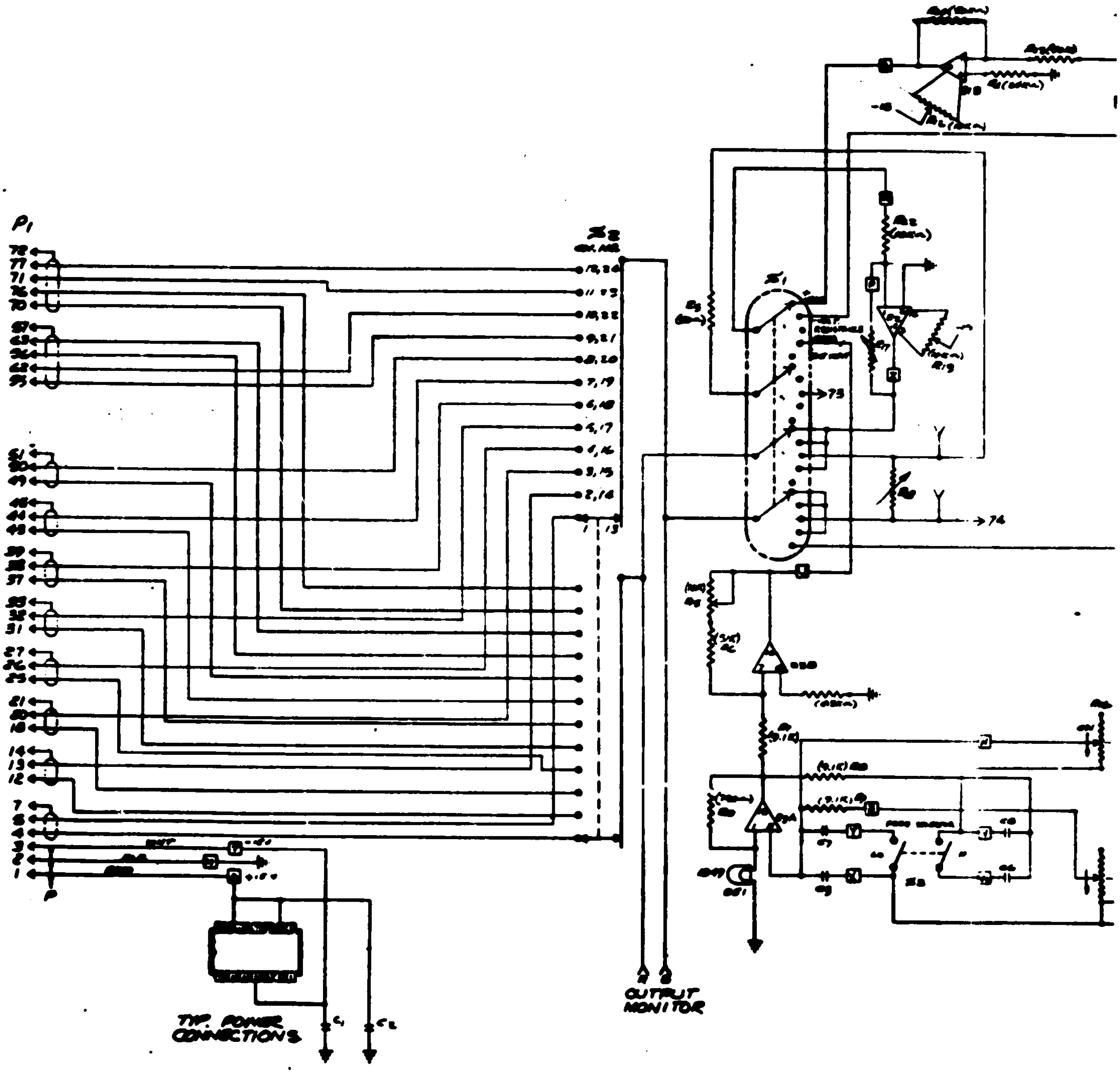
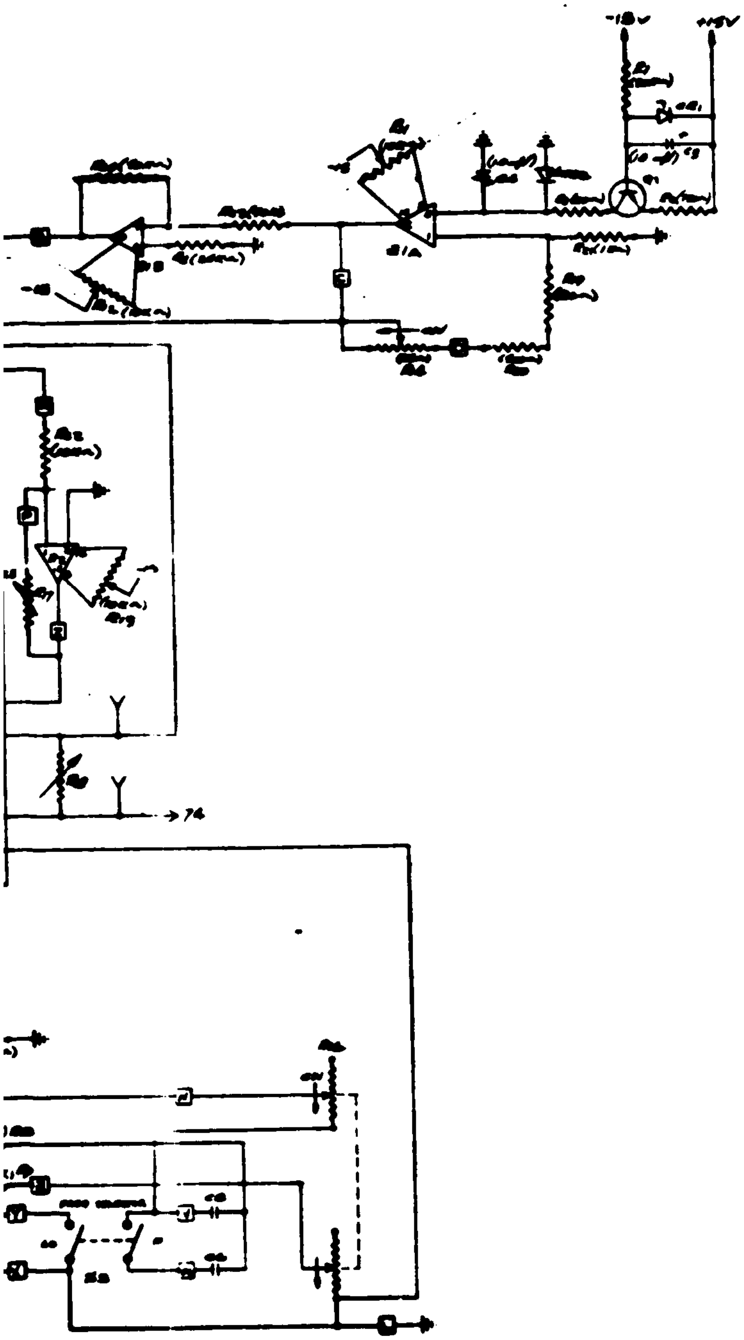


Figure 2–1. Calibrator Schematic



[illegible]	[illegible]	OP AMP	FAIRCHILD	
[illegible]	[illegible]-B1	SWITCH		
[illegible]	PA 2011	SWITCH	CENTRALAB	
[illegible]	PA [illegible]	SWITCH	CENTRALAB	
[illegible]	[illegible]	RESISTOR	0.1%	[illegible]
[illegible]	[illegible] 10KΩ			
[illegible]	[illegible] (1KΩ)			
[illegible]	[illegible]			
[illegible]	[illegible]	RESISTOR	1%	[illegible]
[illegible]	[illegible]	DEKASTAT	ESI	
[illegible]	[illegible]	DEKASTAT	ESI	
[illegible]	[illegible]	RESISTOR	VARIABLE	AB
[illegible]	[illegible]	TRIMPOT	BOURNS	
[illegible]	[illegible]-1-103	TRIMPOT	BOURNS	
[illegible]	[illegible]Ω	RESISTOR	1/4 W	[illegible]
[illegible]	9.1KΩ			
[illegible]	[illegible]Ω			
[illegible]	[illegible]Ω			
[illegible]	[illegible]KΩ			
[illegible]	100Ω			
[illegible]	[illegible]Ω			
[illegible]	[illegible]KΩ	RESISTOR	1/4 W	[illegible]
Q1	[illegible]	TRANSISTOR		
P1	[illegible]	CONNECTOR	WINCHESTER	
[illegible]	[illegible]	LAMP		
[illegible]	IN[illegible]A	DIODE, REFERENCE		
[illegible]	IN[illegible]A	DIODE, REFERENCE		
[illegible]	[illegible]	CAPACITOR	SILVER MICA	
[illegible]	[illegible]		SILVER MICA	
[illegible]	10[illegible]		TANTALUM	

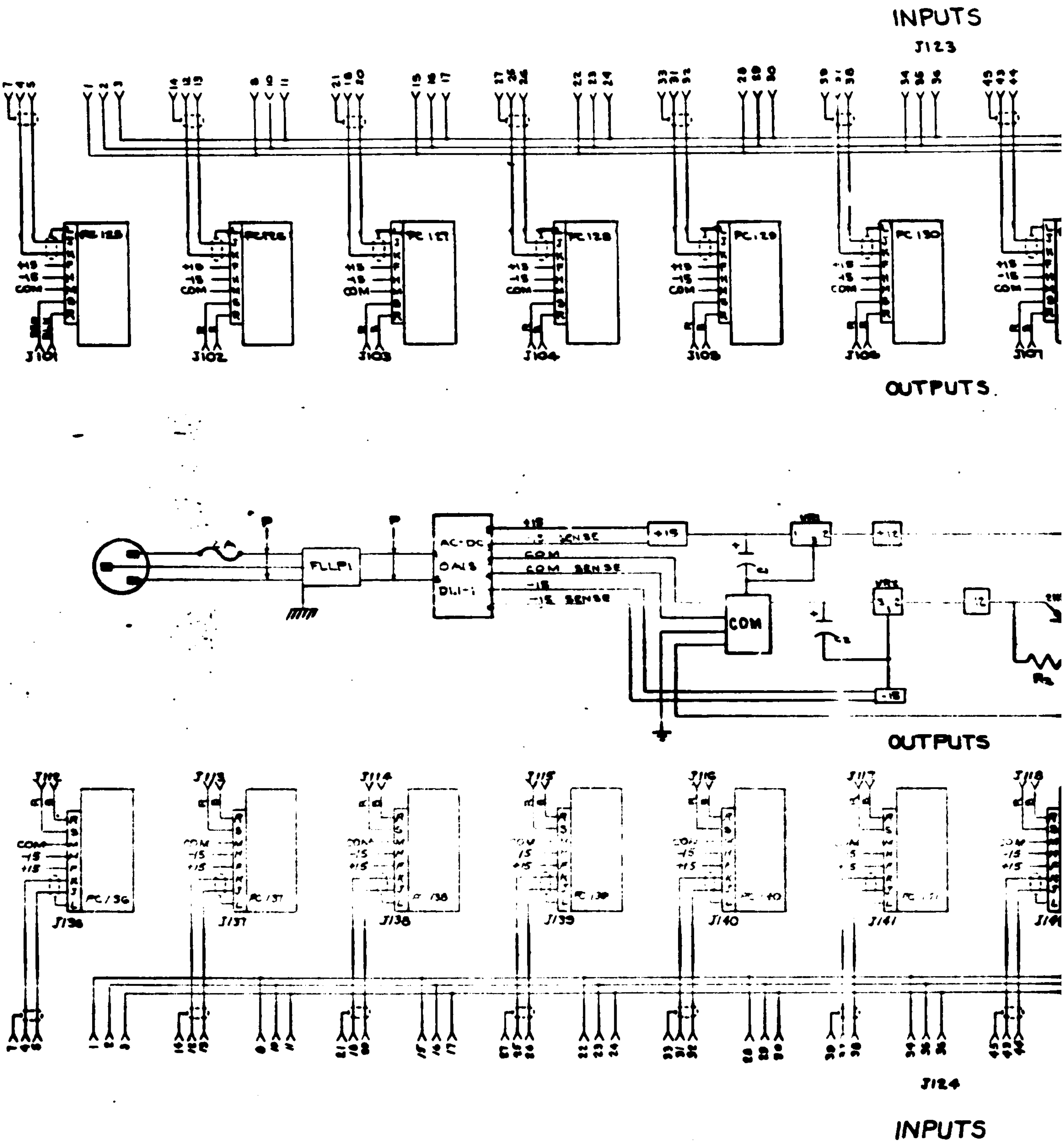
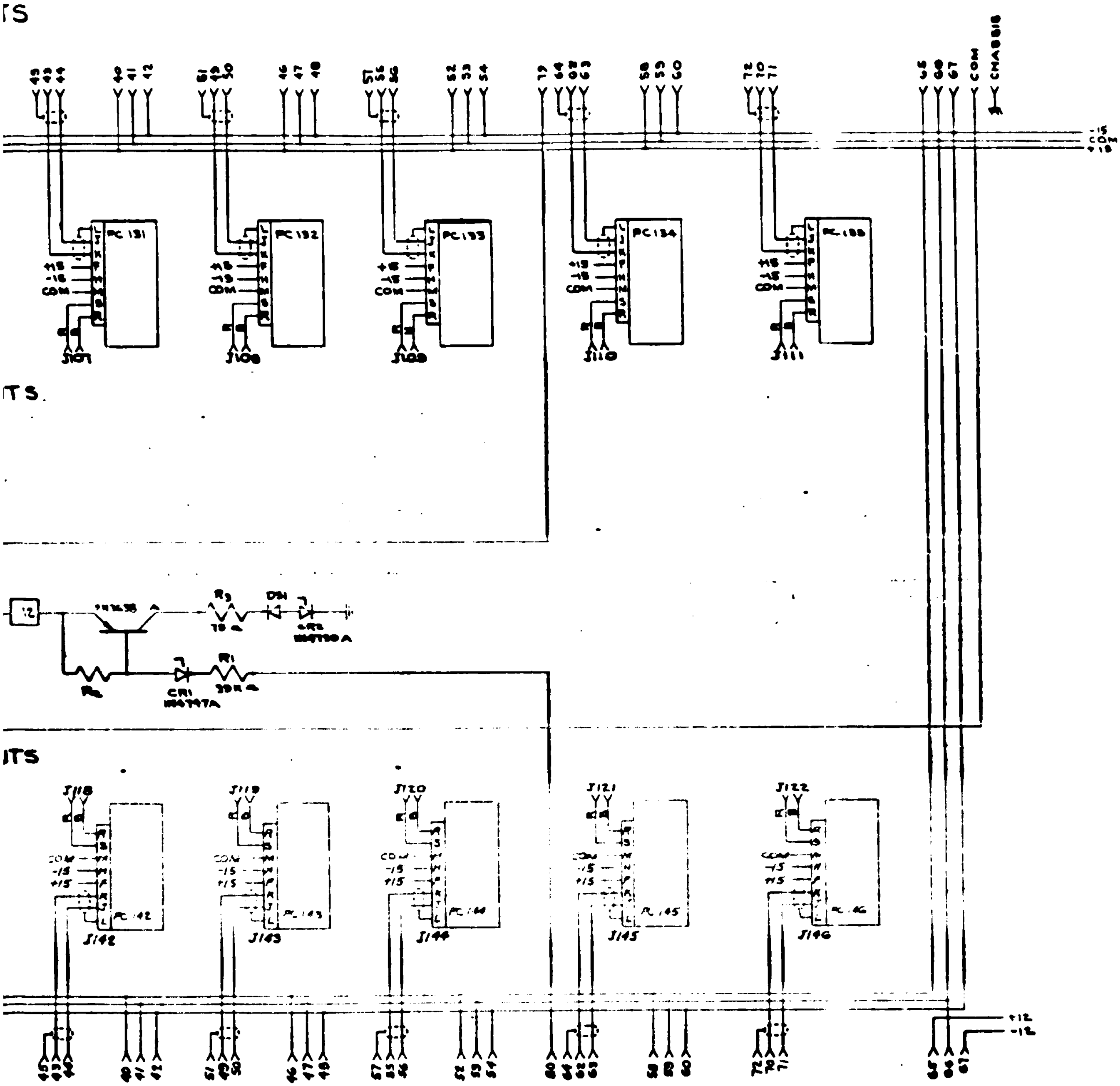
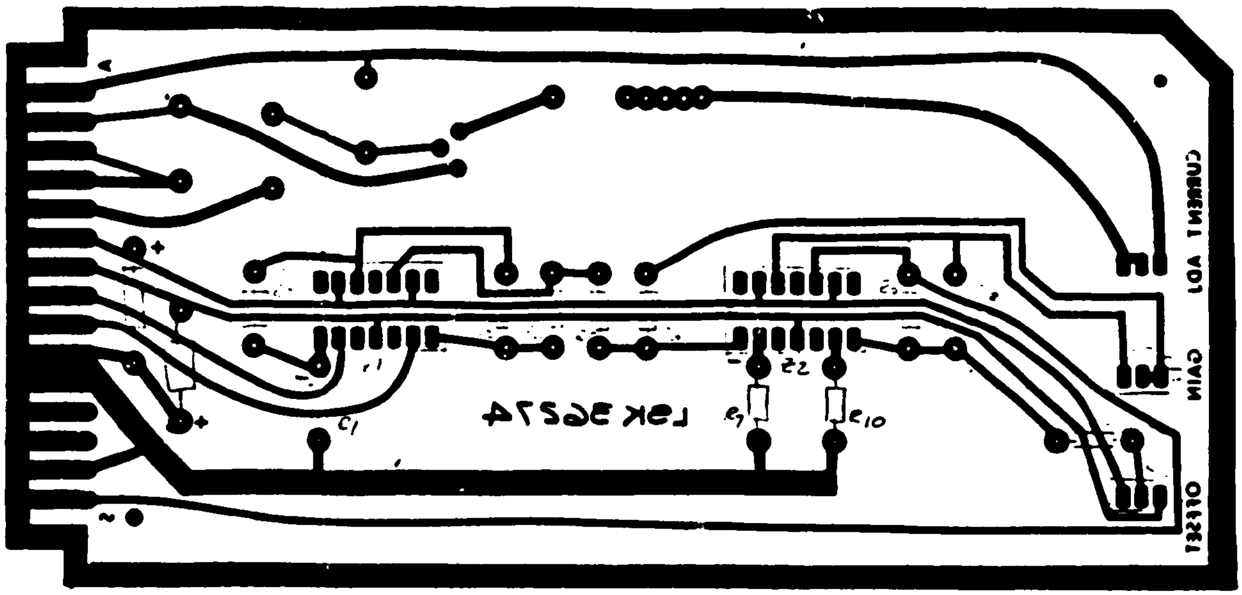


Figure 2–2. Ride Quality Signal Conditioner Schematic



TS

[illegible]	PRINTED CIRCUIT [illegible]
VR2	VOLTAGE REGUL. [illegible]
VR1	VOLTAGE REGU, FAIRCHILD [illegible]
R3	RESISTOR, CARB [illegible] 5% 18 Ω
R2	RESISTOR, CARB [illegible] 5% [illegible]
R1	RESISTOR, CARB [illegible] 5% 39K Ω
Q1	TRANSISTOR 2N3638A
PS1	POWER SUPPLY AC-DC [illegible]
[illegible]	CONN. PC [illegible]
[illegible]	CONN. [illegible]
[illegible]	CONN. [illegible]
FL1	FILTER [illegible]
F1	FUSE [illegible]
DS1	DIODE, LED [illegible]
CR2	DIODE, ZENER [illegible]
CR1	DIODE, ZENER [illegible]
C1, C2	CAPAC. [illegible]



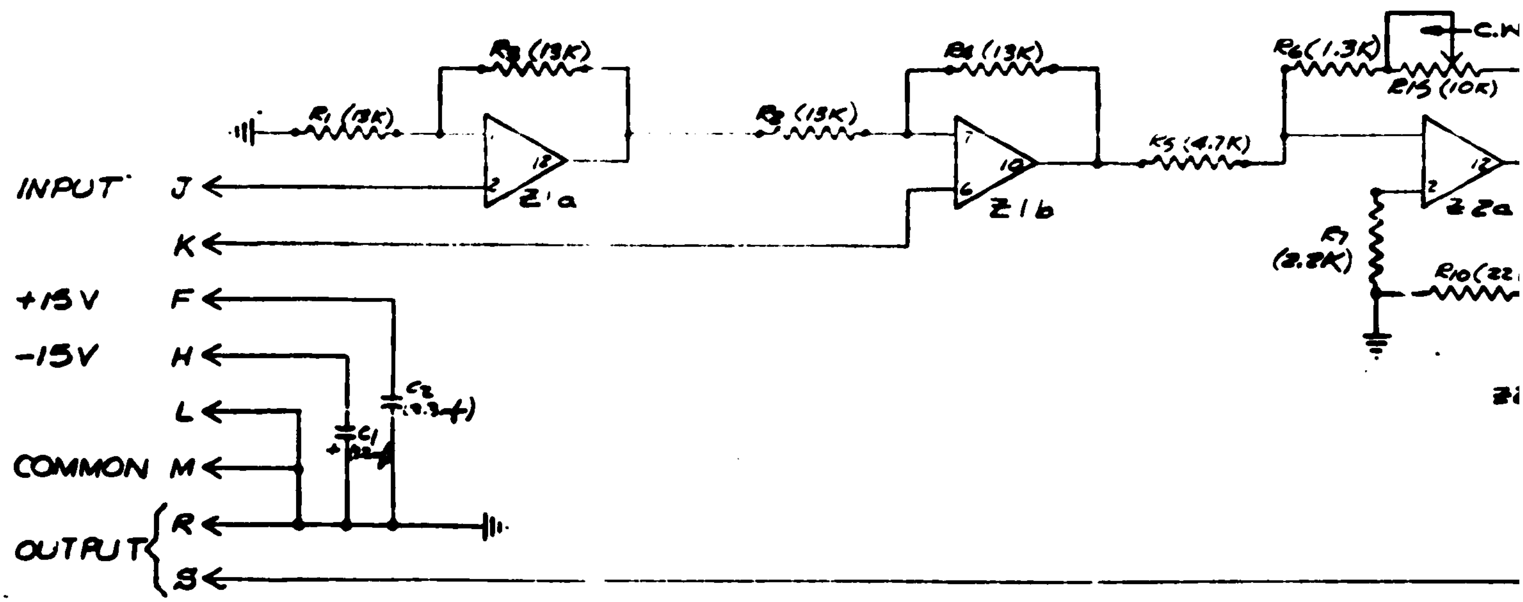
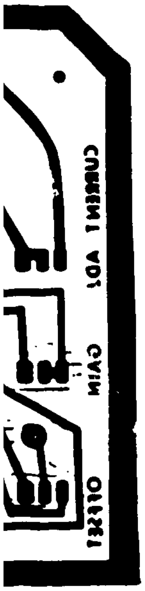
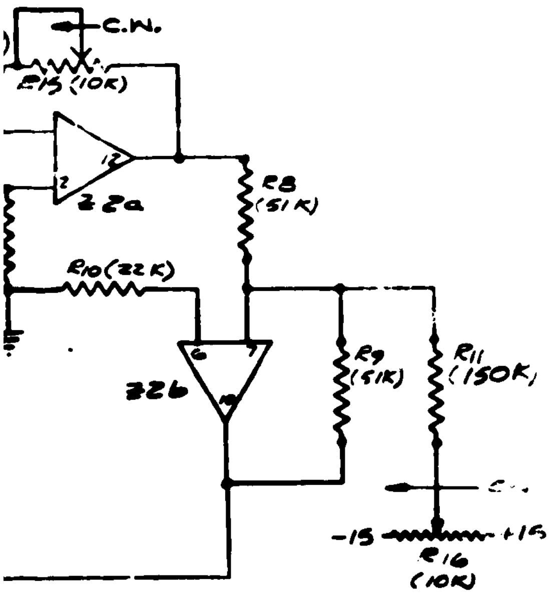


Figure 2–3. Buffer Amplifier Schematic





PC1	CIRCUIT BOARD, PRINTED 6SK362?4
Z1, Z2	OP. AMP. µA7747-312
R5	RESISTOR (4.7K) RL07, 1/4W, 2%
R16, R15	TRIMPOT (10K) 3299 X-1-103 BOURNS
R11	RESISTOR (150K) RL07, 1/4W, 2%
R10	(22K)
R8, R9	(51K)
R7	(2.2K)
R6	(1.3K)
R3, R4	RESISTOR (3K) RL07, 1/4W, 2%
R1, R2	RESISTOR (3K) RL07, 1/4W, 2%
C1, C2	CAPACITOR TANTALUM (3.3 µf)

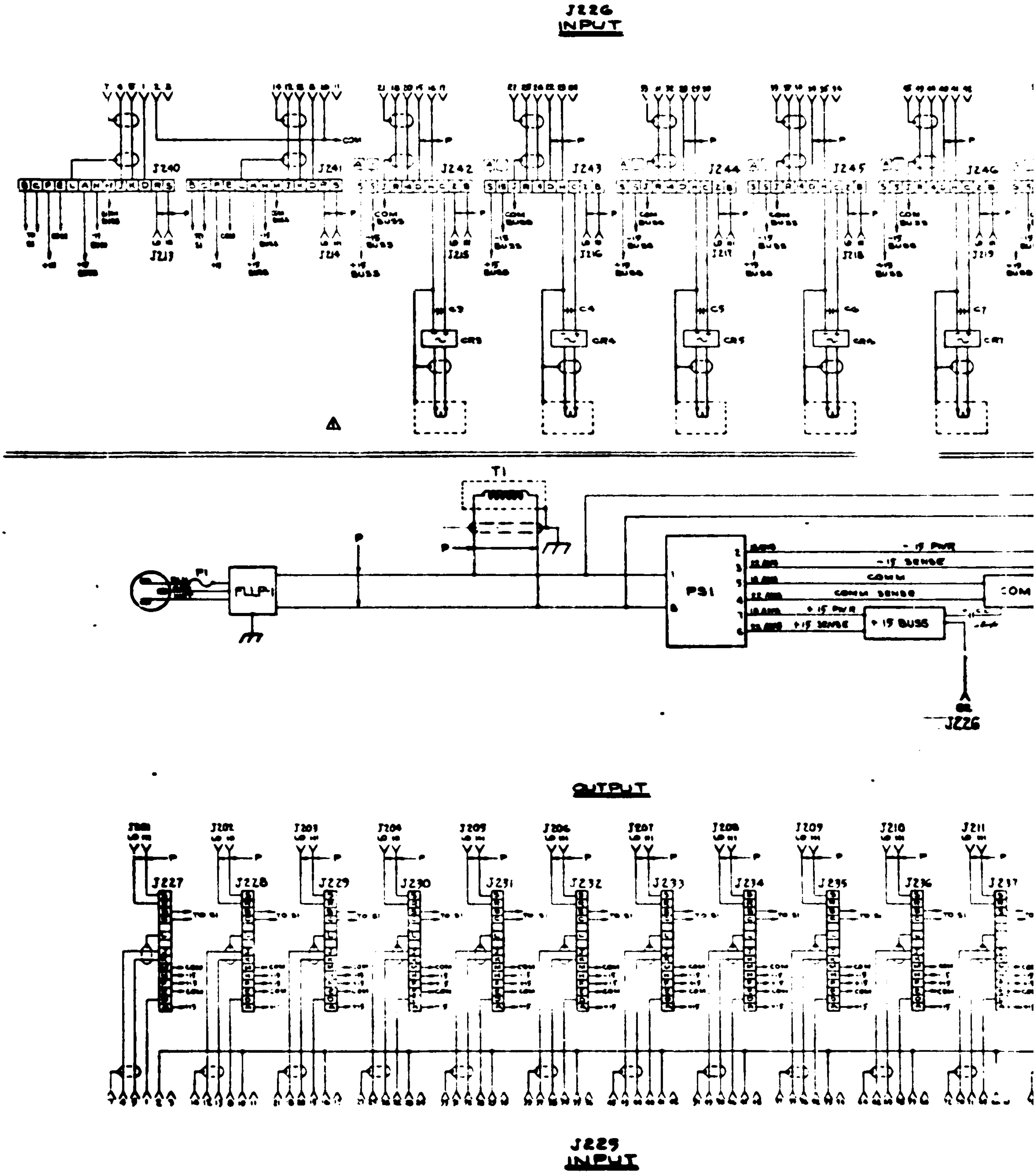
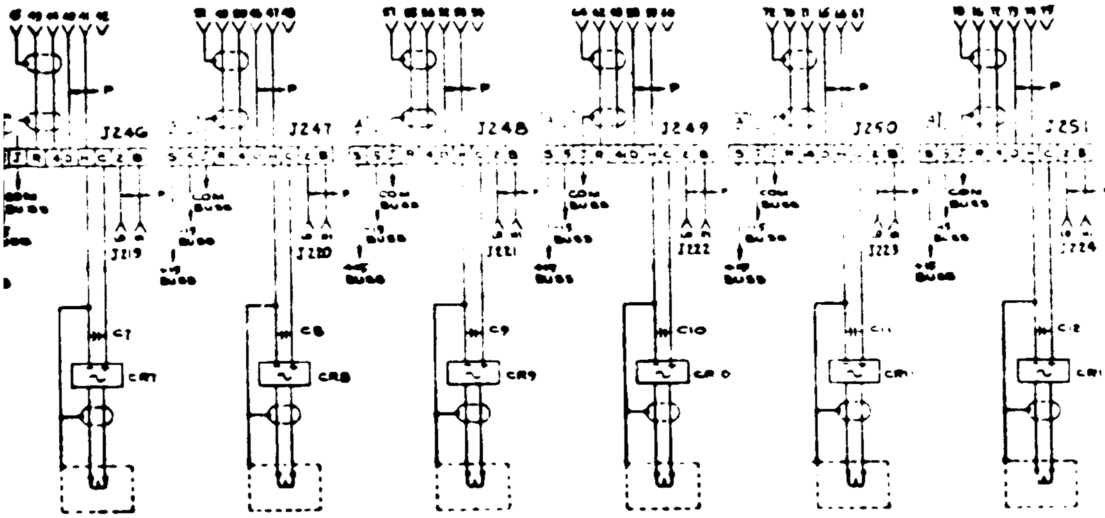
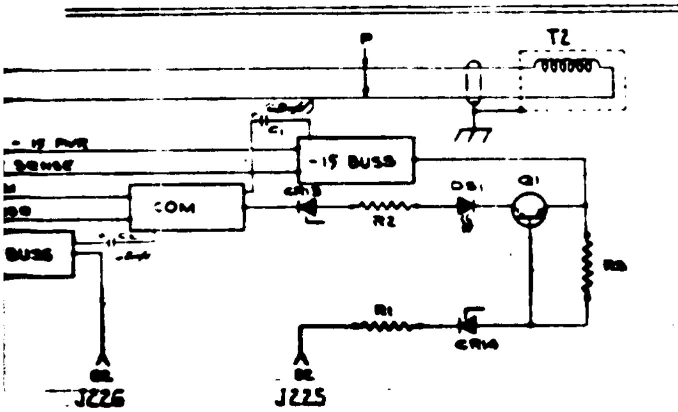
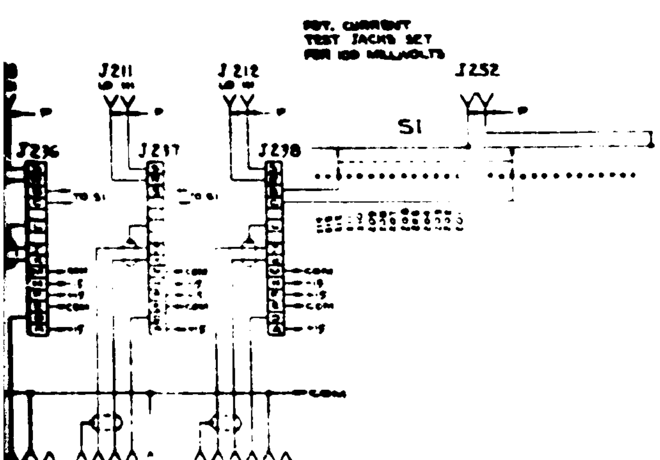


Figure 2–4. Structural Signal Conditioner Schematic







[illegible]	[illegible]	[illegible]	50-30A 30	CONNECTOR	[illegible] JONES
[illegible]	[illegible]	[illegible]	[illegible] 30	CONNECTOR	[illegible] JONES
[illegible]	[illegible]	PS1	[illegible]	POWER SUPPLY [illegible] ELECTRONICS	
[illegible]	[illegible]	Q1	[illegible]	TRANSISTOR	
[illegible]	[illegible]	R1	[illegible]	RESISTOR [illegible]	
[illegible]	[illegible]	R2	[illegible]	RESISTOR [illegible]	
[illegible]	[illegible]	R3	[illegible]	RESISTOR [illegible]	
[illegible]	[illegible]	S1	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	2075	TRANSFORMER	[illegible]
[illegible]	[illegible]	DS1	MV5222	L.E.D.	MONSANTO
[illegible]	[illegible]	CR14	[illegible]	[illegible] ZENER	
[illegible]	[illegible]	CR13	[illegible]	[illegible] ZENER	
[illegible]	[illegible]	[illegible]	[illegible]	DIODE [illegible]	MOTOROLA
[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	CONNECTOR	WINCHESTER
[illegible]	[illegible]	[illegible]	[illegible]	CONNECTOR	WINCHESTER
[illegible]	[illegible]	[illegible]	[illegible]	BANANA JACKS, MIN.	POMONA
[illegible]	[illegible]	F1	[illegible]	FUSE [illegible]	BUS-[illegible]
[illegible]	1	[illegible]	[illegible]	CAPACITOR [illegible]	[illegible]

The excitation currents for the resistive transducers are monitored by a switch and test jacks on the rear panel. The numbers 201 to 214 correspond to the like numbered cards in the rack. The output at the test jacks should be one hundred millivolts for each channel. This can also be used to ascertain if all transducers have continuity by switching through all channels and observing the voltage at the test jacks. Zero voltage indicates an open transducer.

Cards 215 to 220 are AC coupled strain gage amplifiers. These amplifiers monitor structural members of the train and the large static load must be suppressed by AC coupling.

Cards 221 to 224 are DC coupled strain gage amplifiers. Cards 221 through 223 are used for three angular accelerometers. Channel 224 is a spare.

The circuit for conditioning the signal from a resistive displacement transducer is shown in Figure 2-5. This card is divided into two parts. A constant current source section generates a constant current of 5 milliamps into the transducer load. The transducer resistance varies from zero to one thousand ohms. The voltage developed across the transducer is directly proportional to the transducer resistance. A 20 ohm precision resistor is in series with the transducer excitation current. It provides a monitor point to set the current to exactly 5 milliamps (100 millivolts across 20 ohms).

The voltage developed across the transducer is proportional to its resistance only as long as no shunting resistance is placed across the transducer. Therefore, Z1 (Figure 2-5) and its associated resistors are designed to form an infinite input impedance differential amplifier. This amplifier can be connected across the transducer without destroying its linearity. Amplifier Z2A (Figure 2-5) provides variable gain, and Z2B (Figure 2-5) provides a means to achieve zero offset.

The strain gage signal conditioning circuit is shown in Figure 2-6. This board was designed to condition any four-arm strain gage bridge. It contains a bridge excitation regulator and amplifier. The regulator provides five volts DC for bridge excitation. The amplifier section comprises three stages of operational amplifiers. The overall gain of the card may be varied from 50 to 1000.

The first stage of amplification uses an instrumentation grade amplifier (μ5T7725). This amplifier is connected as a fixed gain differential input preamplifier. There are three trimpots on this first stage. The first two provide independent adjustment of the inverting and non inverting gains over a small range (+2%). These pots are used to adjust the stage for maximum common mode rejection. The third trimpot is used to set the output zero level of the stage.

The second stage is a variable gain amplifier with a gain range of X0.5 to X10. The gain pot is located on the edge of the card. The output zero of this second stage is adjusted by a trimpot.

The third state is a fixed gain amplifier similar to stage two with a fixed gain of 10. The output zero control for stage three is a trimpot. Pads are also provided in the third stage feedback loop for capacitors used to roll off high frequency noise. The output of the third amplifier then goes to a set of jacks used to provide polarity reversal.

Trimpot and switch functions (mounted on the edge of the board) are from top to bottom (Figure 2-6):

R_2 = This pot, in conjunction with a push-in resistor, provides bridge balance control.

R_3 = Amplifier gain control

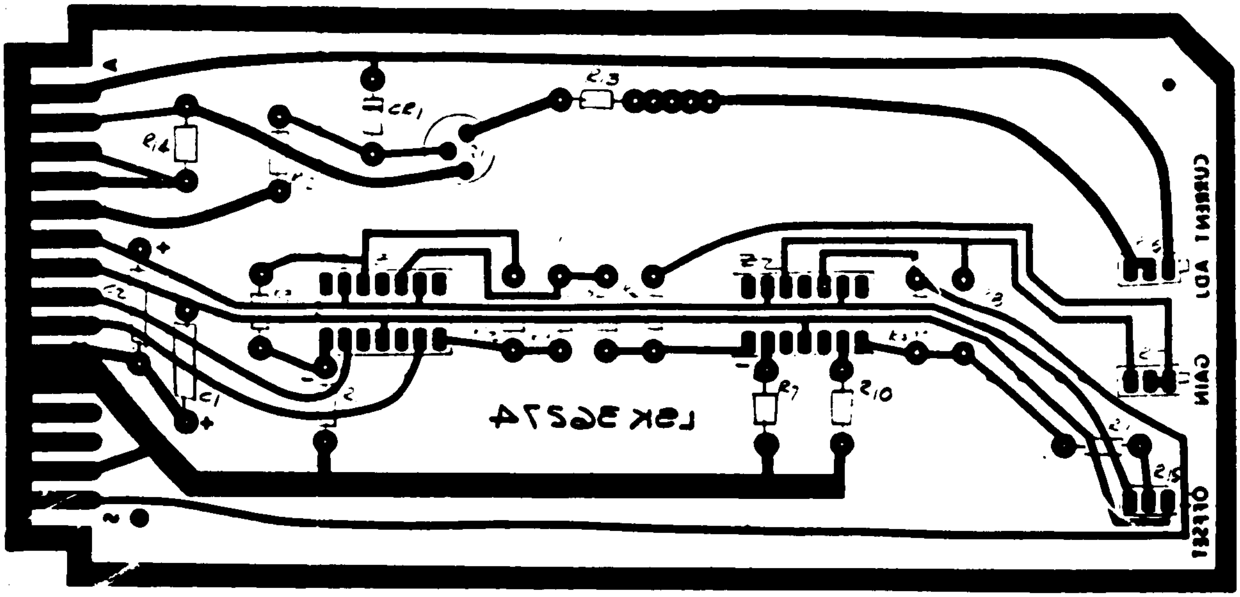
S_1 = This switch selects plus or minus resistance calibration.

2.2.3 Performance Signal Conditioner: Description and Theory of Operation

The sixteen parameters that comprise the data for evaluating vehicle performance are as follows: linear acceleration, four wheel speeds, third rail current, line voltage, "P" current, two traction motor voltages, four traction motor currents (armature and field), brake valve current, and brake air pressure. The Performance Conditioner panel contains electronic modules for conditioning these parameters for recording purposes. In addition, the panel contains electronic modules that compute the electrical power used by the vehicle and generate a series of pulses to indicate total energy consumption. A wiring diagram is shown in Figure 2-7.

Linear longitudinal acceleration is measured by a linear accelerometer, similar to the accelerometers used for measuring ride quality. Signal conditioning is provided by Card 301. This card is identical to the circuit cards in the Ride Quality panel.

The three voltages and seven currents are sensed respectively by voltage dividers and current transducers. The resulting signals are conditioned by Cards 302 through 311. These ten cards have identical circuits, shown in Figure 2-3. The circuit of the remote boxes which divide and isolate the high



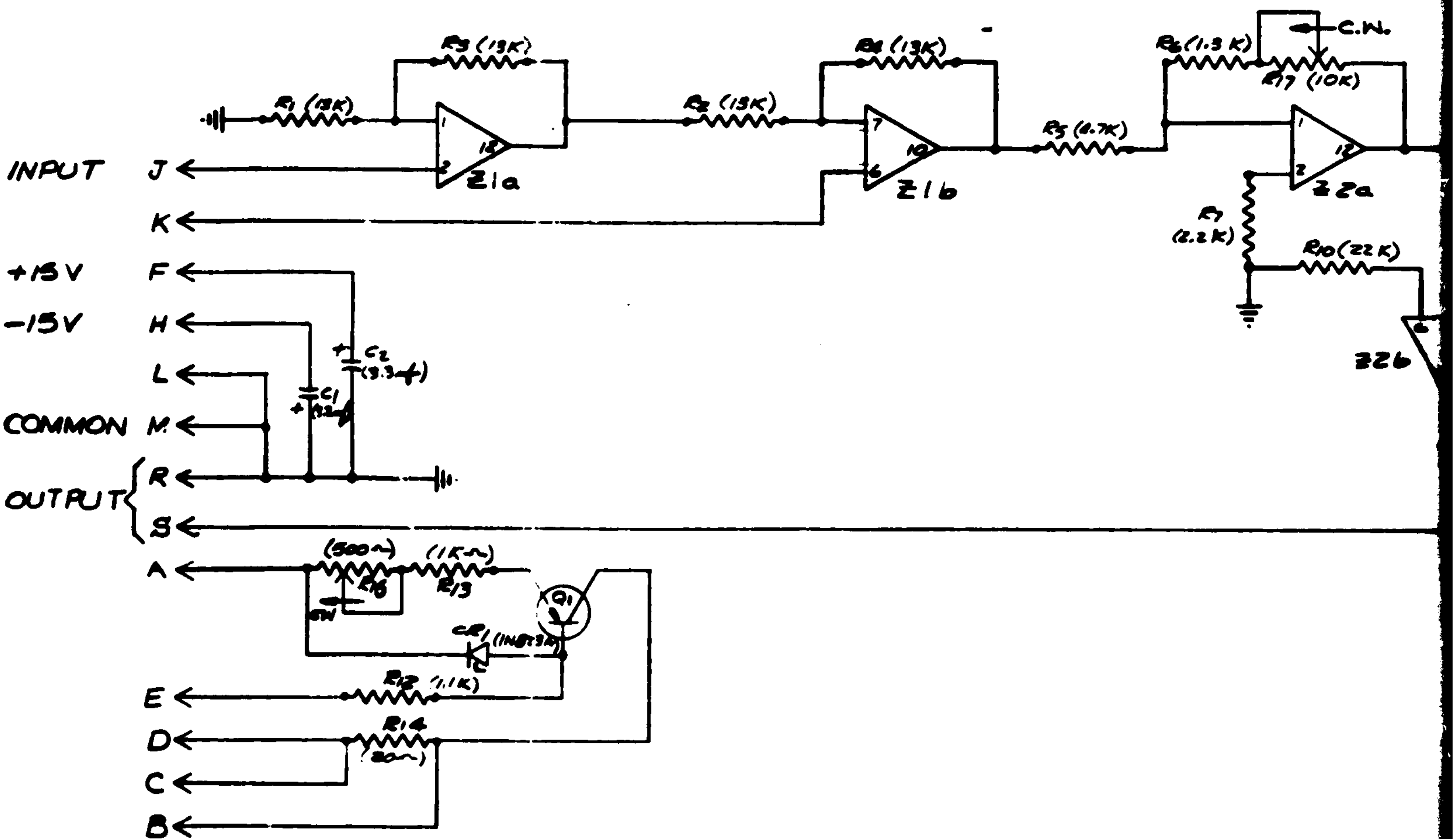
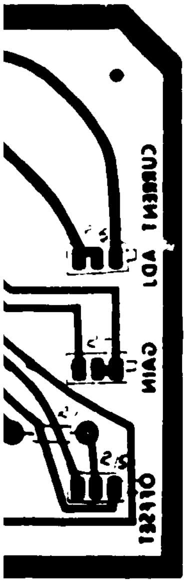
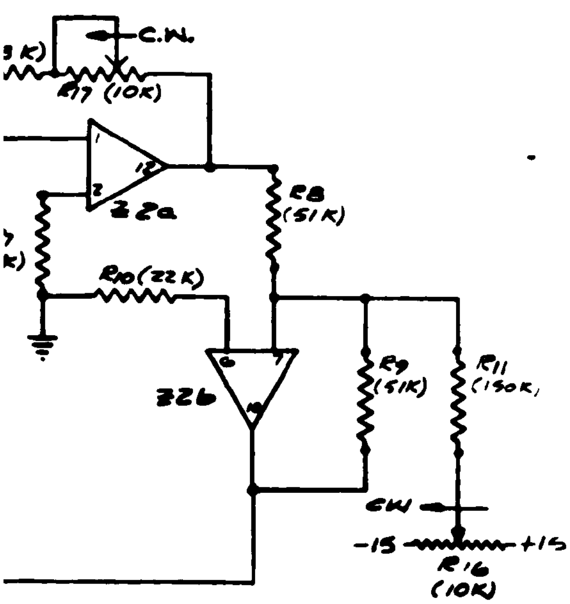
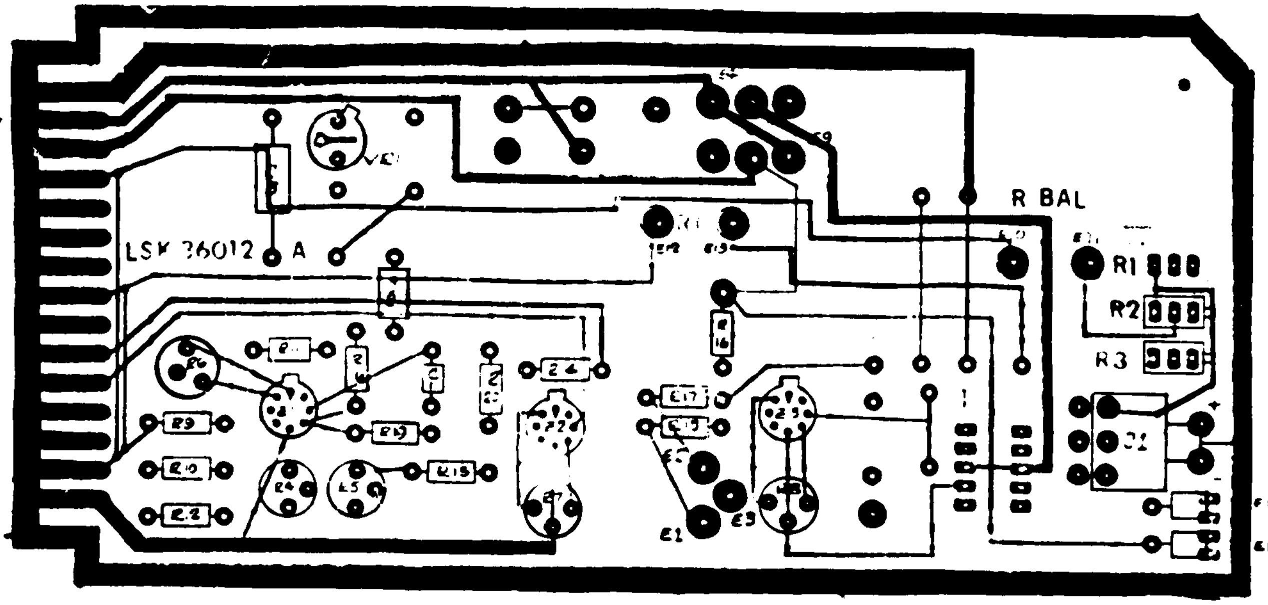


Figure 2–5. Displacement Buffer Amplifier Schematic





Z1, Z2	OP. AMP. μA7747-312
PC1	CIRCUIT BOARD, PRINTED LSK36274
Q1	TRANSISTOR 2N3638A
CR1	DIODE, ZENER 1N823A
R16	TRIMPOT 3289W-68-501 BOURNS
R15, R17	TRIMPOT 3299X-1-103 BOURNS
R14	RESISTOR (20Ω) JORDAN S-180 1/8W, 1/2%
R13	(1KΩ) JORDAN S-180 1/4W, 1/2%
R12	(1.1KΩ) RLO7 1/8W, 2%
R11	(150KΩ)
R10	(22KΩ)
R8, R9	(51KΩ)
R7	(2.2KΩ)
R6	(1.3KΩ)
R5	(4.7KΩ)
R1, R2, R3, R4	RESISTOR 13 KΩ, RL07 1/4W, 2%
C1, C2	CAPACITOR TANTALUM (3.3 μF)



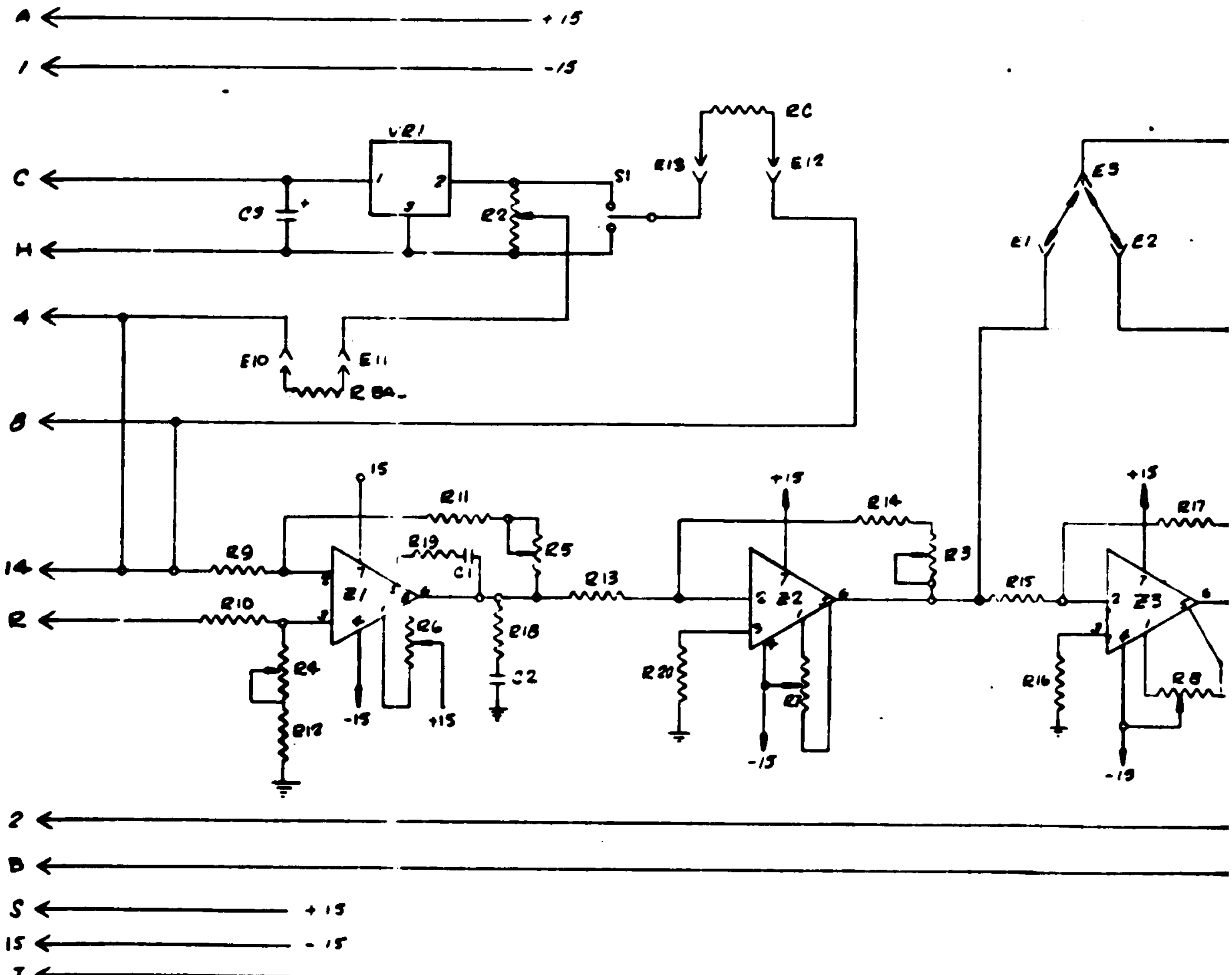
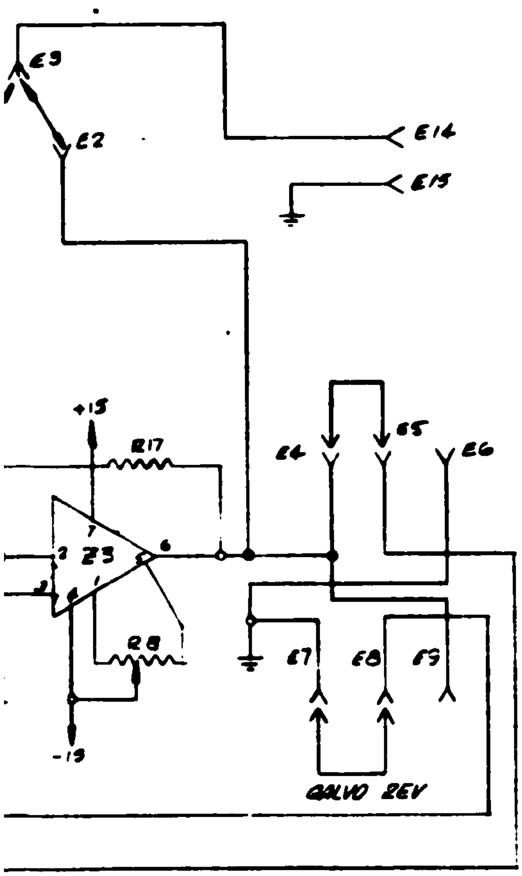


Figure 2–6. DC Strain Gage Amplifier Schematic



R20	RL07	RESISTOR 1/4 2% 390 Ω
Z2,Z3	U5B7741-312	OP-AMP FAIRCHILD
Z1	U5T7725-312	OP-AMP FAIRCHILD
VR1	LM 309H	VOLTAGE REGULATOR N.S.C.
S1	7O2-221	SWITCH, JBT
R19	RL07	RESISTOR 1/4 W 2% 270 Ω
R18	RL07	27 Ω
R17	RL07	100K Ω
R16	RL07	9.1K Ω
R15	RL07	RESISTOR 1/4 W 2% 10K Ω
R14	S-180 500	RESISTOR 1/2% JORDAN
R13	S-180 1K Ω	
R11,R12	S-180 1MEG Ω	
R9,R10	S-180 100K Ω	RESISTOR 1/2% JORDAN
R7,R8	3339P-1-103	TEMPOT, BOURNS 10K Ω
R6	3339P-1-104	100K Ω
R4,R5	3339P-1-203	[illegible] Ω
R2,R3	3339X-1-103	TEMPOT, BOURNS 10K Ω
E14-E15	3422-1-79	TEST JACK, CAMBION
E10-E13	3397-2-03	COMPONENT JACK CAMBION
E1-E9	3389-1-03	TEST JACK CAMBION
C3	.33 MFD	CAPACITOR TANTALUM
C1	[illegible]	CAPACITOR ELPAC .0015 MFD
C2	[illegible]	CAPACITOR ELPAC .047 MFD

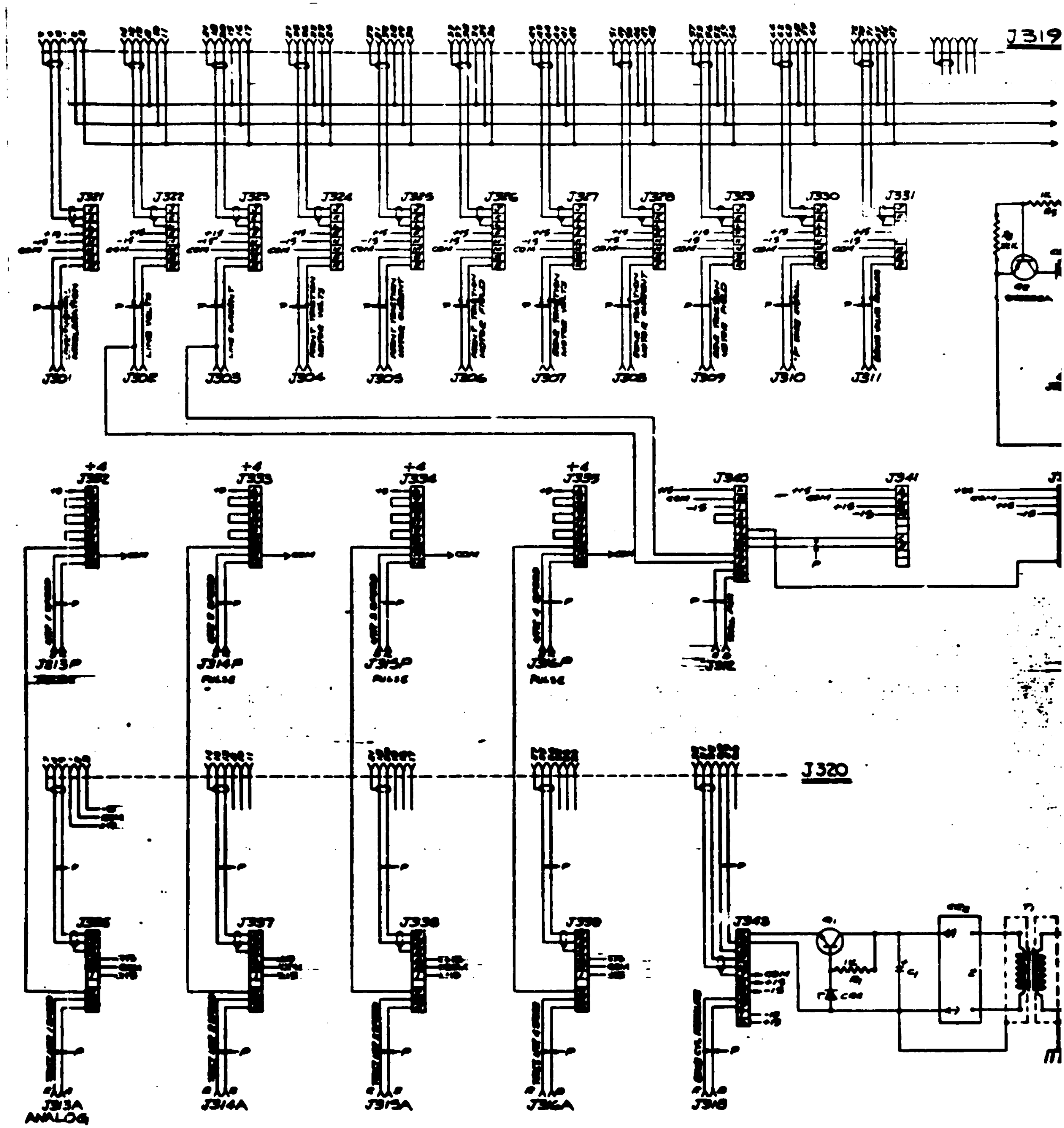
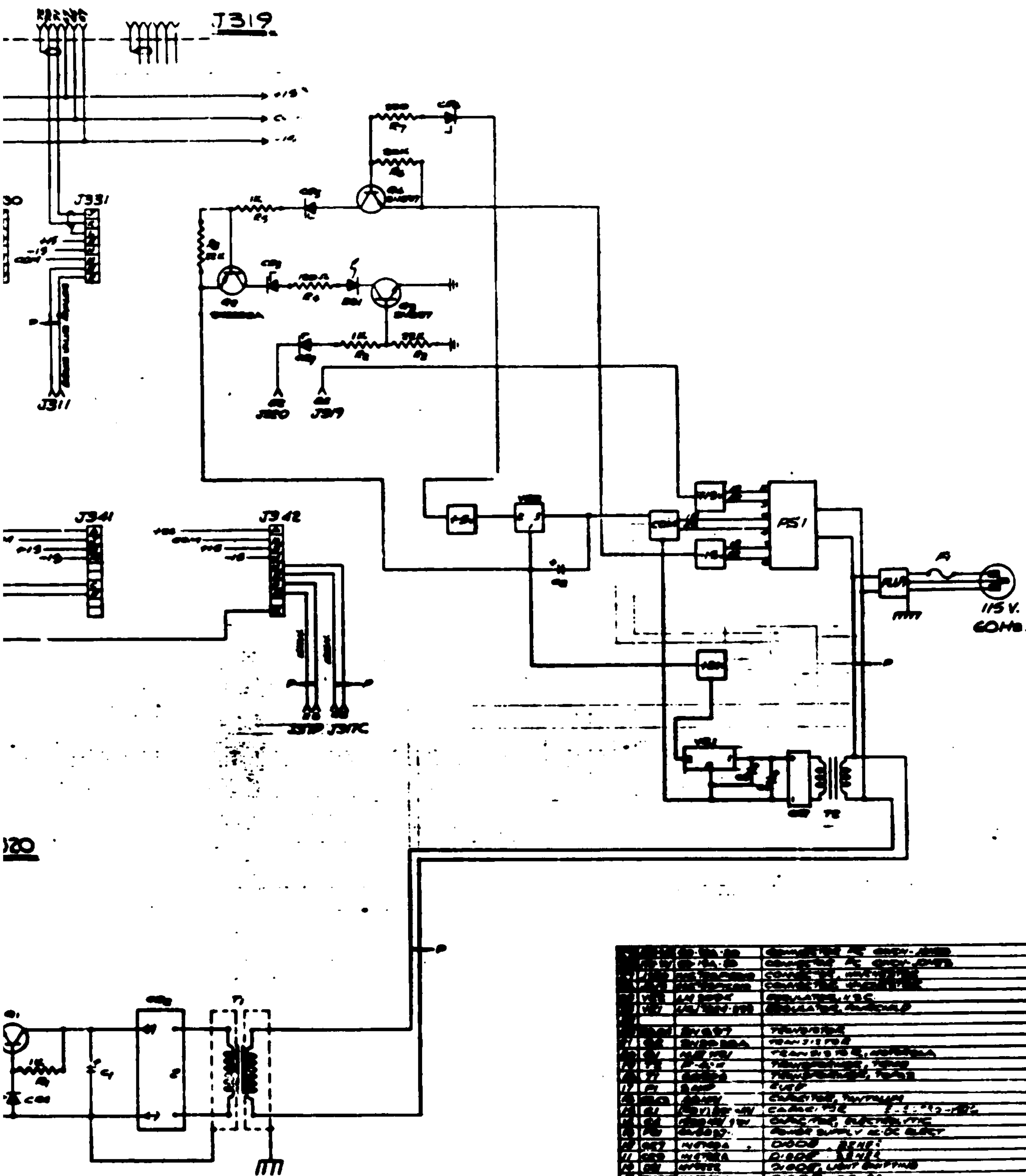


Figure 2–7. Performance Signal Conditioner Schematic



[illegible]	[illegible]	[illegible]	CONNECTOR PC [illegible]
[illegible]	[illegible]	[illegible]	CONNECTOR PC [illegible]
[illegible]	[illegible]	[illegible]	CONNECTOR, [illegible]
[illegible]	[illegible]	[illegible]	CONNECTOR, [illegible]
[illegible]	VR1	[illegible]	REGULATOR, +5C
[illegible]	VR2	[illegible]	REGULATOR, [illegible]
[illegible]			
[illegible]	[illegible]	[illegible]	TRANSISTOR
[illegible]	[illegible]	[illegible]	TRANSISTOR
[illegible]	[illegible]	[illegible]	TRANSISTOR, [illegible]
[illegible]	[illegible]	[illegible]	TRANSFORMER, [illegible]
[illegible]	[illegible]	[illegible]	TRANSFORMER, [illegible]
[illegible]	F1	[illegible]	FUSE
[illegible]	[illegible]	[illegible]	CAPACITOR, TANTALUM
[illegible]	C1	[illegible]	CAPACITOR [illegible]
[illegible]	[illegible]	[illegible]	CAPACITOR, ELECTROLYTIC
[illegible]	[illegible]	[illegible]	POWER SUPPLY AC-DC [illegible]
[illegible]	[illegible]	[illegible]	DIODE, ZENER
[illegible]	[illegible]	[illegible]	DIODE, ZENER
[illegible]	[illegible]	[illegible]	DIODE, LIGHT EMITTING
[illegible]	[illegible]	[illegible]	DIODE, ZENER
[illegible]	[illegible]	[illegible]	DIODE BRIDGE, MOTOROLA
[illegible]	[illegible]	[illegible]	LINE FILTER [illegible]
[illegible]			
[illegible]	[illegible]	[illegible]	RESISTOR ([illegible])
[illegible]	[illegible]	[illegible]	RESISTOR ([illegible])
[illegible]	[illegible]	[illegible]	RESISTOR ([illegible])
[illegible]	[illegible]	[illegible]	RESISTOR ([illegible])
[illegible]	[illegible]	[illegible]	RESISTOR [illegible]

voltage is shown in Figure 2-8. The voltage ratio is 1:200, such that an input range 0-1000 volts corresponds to an output range of 0 to 5 volts. The current sensors are magneto-resistive transducers, manufactured by American Aerospace.

The four wheel speed signals are conditioned by frequency-to-DC converters to provide an analog of speed for direct recording on the oscillographs, and a pulse output to record directly on magnetic tape. The pulse outputs are routed through frequency division cards.

The kilowatt-hour computer consists of three cards, an analog multiplier, a DC-to-frequency converter, and a frequency divider and power driver. These circuits are shown in Figures 2-9 and 2-10. The voltage and current signals are scaled such that zero equals minus five volts and full scale equals plus five volts. These are fed to the analog multiplier input amplifiers, shown in Figure 2-9. The non inverting input of the multipliers are referenced at minus five volts. This reference converts the voltage and current analogs to a zero to ten volt range. The multiplier computes the instantaneous product; its output is scaled to the range of 0 to 10 volts DC. The amplifier gains are adjusted such that this range corresponds to a power range of 0 to 2 megawatts.

The output of the multiplier is applied to the DC-to-frequency convertor card, the circuit of which is shown in Figure 2-10. The signal is applied to a scaling amplifier. This amplifier provides a differential gain of X0.10. The zero to one volt signal from this stage is applied to a low pass, two pole filter stage. This filter stage provides a signal averaging time of 700 milliseconds, and also provides noise rejection for frequencies above two Hertz (40 DB per decade above 2Hz). The output of this filter stage drives a DC-to-frequency converter stage. This converter uses an input of 0 to +1 volts DC to generate a pulse output frequency of 0 to 556 Hz. The output level is 0 to -4 volts DC. These pulses are then level shifted to form a 0 to +15 volt DC pulse suitable for driving the high-level logic stages that follows.

The pulse train is applied to the input stage of the frequency divider and driver card, also shown in Figure 2-10. These 0 to +15 volt DC pulses are then applied to a series of two decade counters (type 371). Each decade counter divides the input frequency by ten; thus, two counters provide a division of one hundred. The 0 to +15 volt transitions of the divided pulse chain fire a one-shot circuit (type 342) which provides an 80 millisecond output pulse for each positive-going input transition. The 80 millisecond output pulse drives a Darlington-connected transistor pair, which provides a zero to +24 volt dc pulse to an electromechanical counter. The subsystem voltage versus frequency conversion ratio is set so that the number displayed by the electromechanical counter is direct reading in units of kilowatt hours used by the train propulsion system.

The scaling of amplifier gains to achieve a counter display in units of tenth kilowatt hours is shown in the following example:

E_1 = Input level to KWH subsystem (in volts)

E_2 = Input level to DC/Freq converter (in volts)

F_0 = Frequency output of DC/Freq converter (in Hz)

P = Power consumption of train car pair (in kilowatts)

W = Energy consumption of train car pair (in kilowatt-hours)

Equation 1

$$E_1 = K_1 P$$

where

$$K_1 = \frac{E1\ max}{P\ max} = \frac{10V}{2000\ kw} = 0.005\ V/kw$$

Equation 2

$$E_1 = 0.005P$$

$$E_2 = \text{Gain of } A_2 \times E_1$$

$$E_2 = 0.1E_1 = 0.0005P$$

$$E_2\ max = 0.1\ E_1\ max = 0.1\ (10) = 1.0\ volt$$

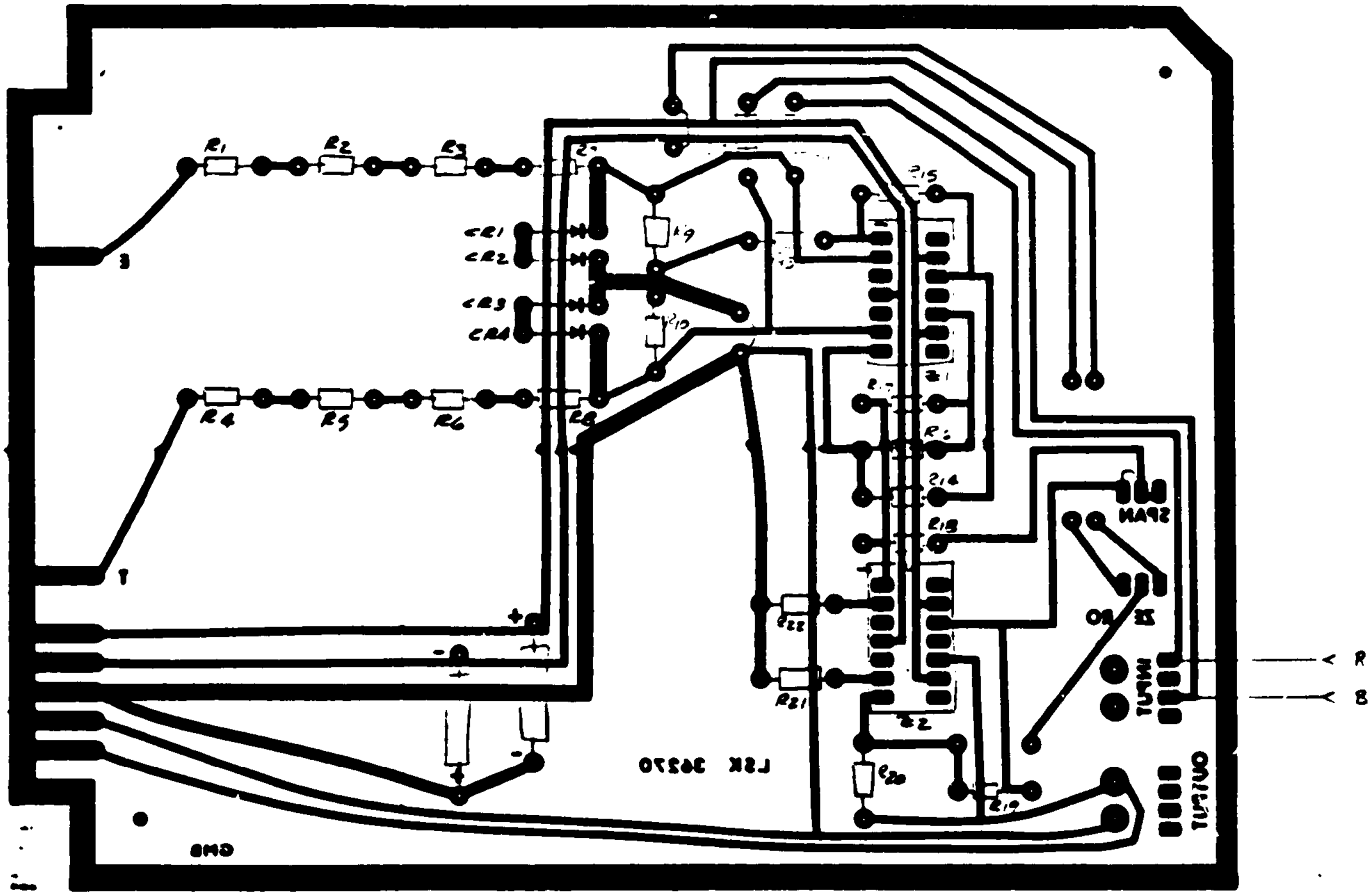
Equation 3

$$F_0 = K_2\ E_2$$

where

$$K_2 = \frac{\text{Total counts}}{\text{Time (sec)}} = \frac{20,000}{3,600} = 5.555$$

$$F_0 = 5.555\ E_2 = 0.002777P$$



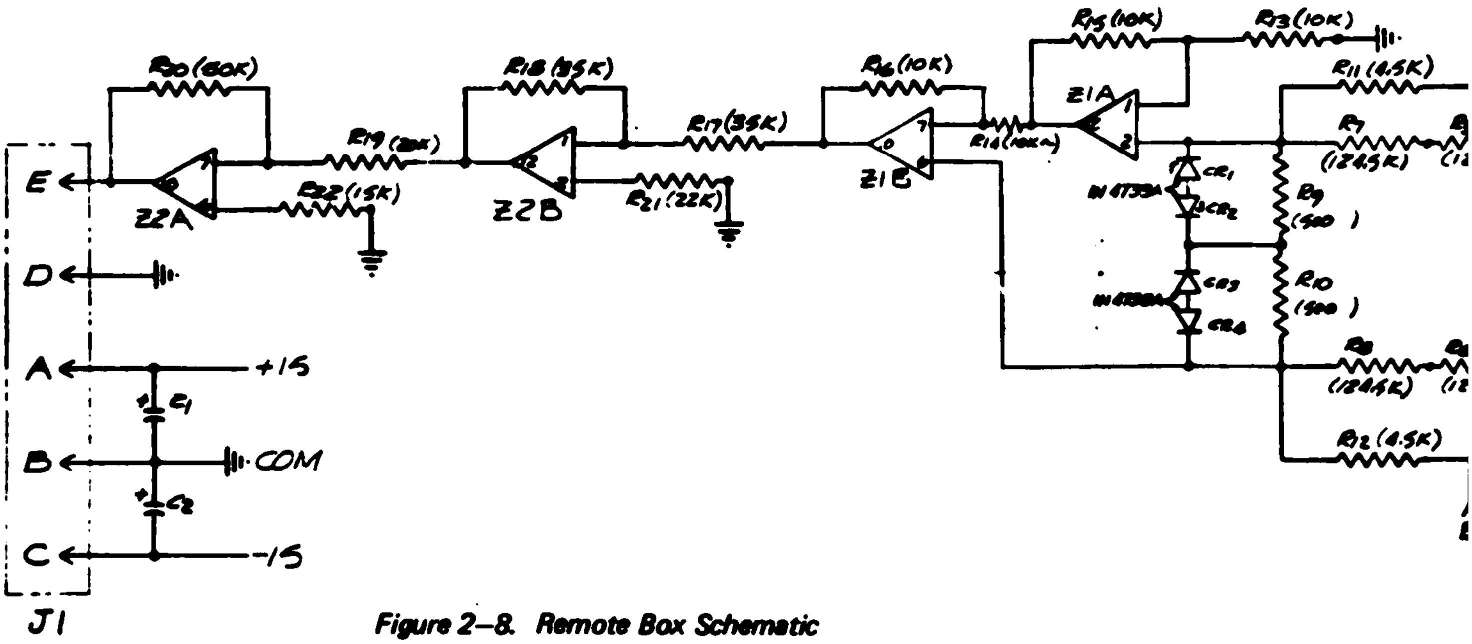
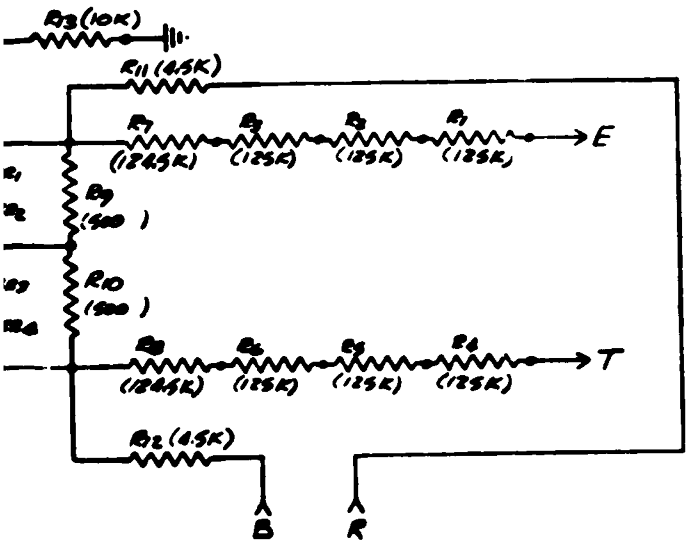


Figure 2–8. Remote Box Schematic

Z_1, Z_2	OP AMP μa 7747-312
:	
R22	RESISTOR RL07 15KΩ, 1/4 W, 2%
R21	RL07 22KΩ, 1/4 W, 2%
R20	5180 50KΩ, 1/2 %
R19	20KΩ, 1/2 %
R18	35KΩ, 1/2 %
R17	5180 35KΩ, 1/2 %
R13-R16	A01RL 10KΩ, .1%
R11, R12	4.5KΩ, .1%
R9, R10	500 Ω, .1%
R7, R8	124.5KΩ, .1%
R1, R2, R3, R4, R5, R6	RESISTOR, A01RL 125KΩ, .1%
PC1	PRINTED CIRCUIT BOARD (LSK 36270)
:	
J1	CONNECTOR, BENDIX (PT07P-10-6P)
CR1, CR2, CR3, CR4	DIODE, ZENER (1N4733A)
C1, C2	CAPACITOR, TANTALUM [illegible]



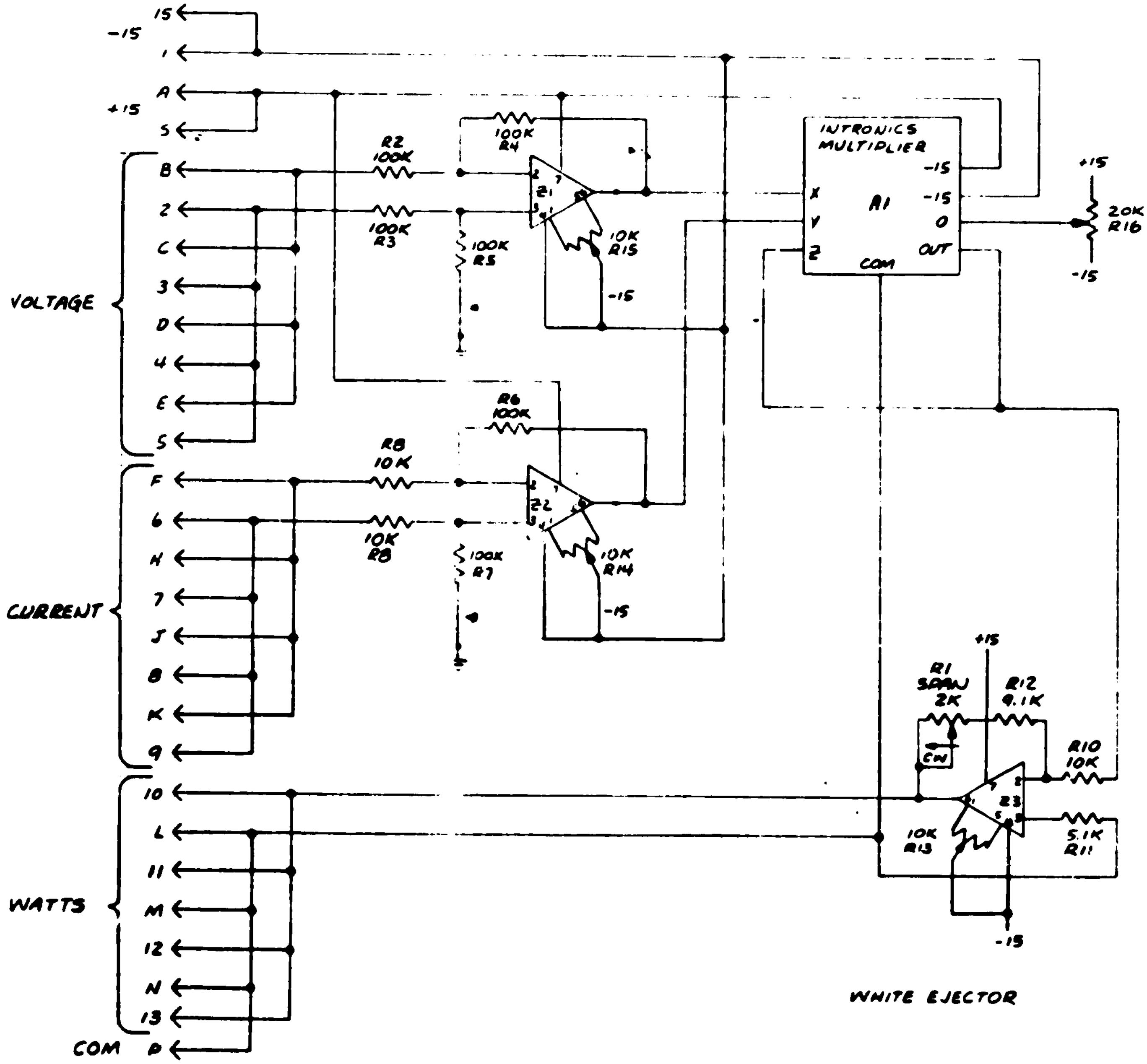
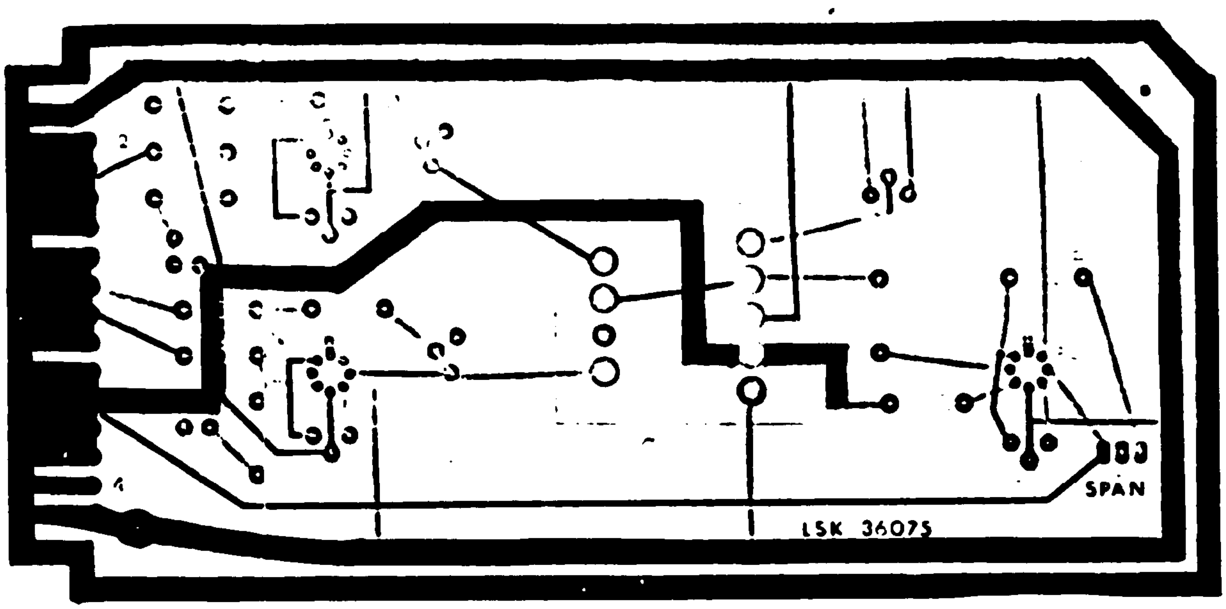


Figure 2–9. Wattmeter Multiplier Schematic

20K
R16



PC 1

Z1 - Z3	OP-AMP FAIRCHILD USB 7741-312
R16	POT BOURNS 20KΩ 3339P-1-203
R13-R15	POT BOURNS 10KΩ 3339P-1-103
R12	9.1KΩ
R11	5.1KΩ
R8-R10	10KΩ
R2-R7	RESISTORS 100KΩ 1/4 WATT 2% RL07
R1	POT BOURNS 3282H-1-202 2KΩ
A1	MULTIPLIER MODULE [illegible] M 416
PC 1	PC BOARD LSK 36075

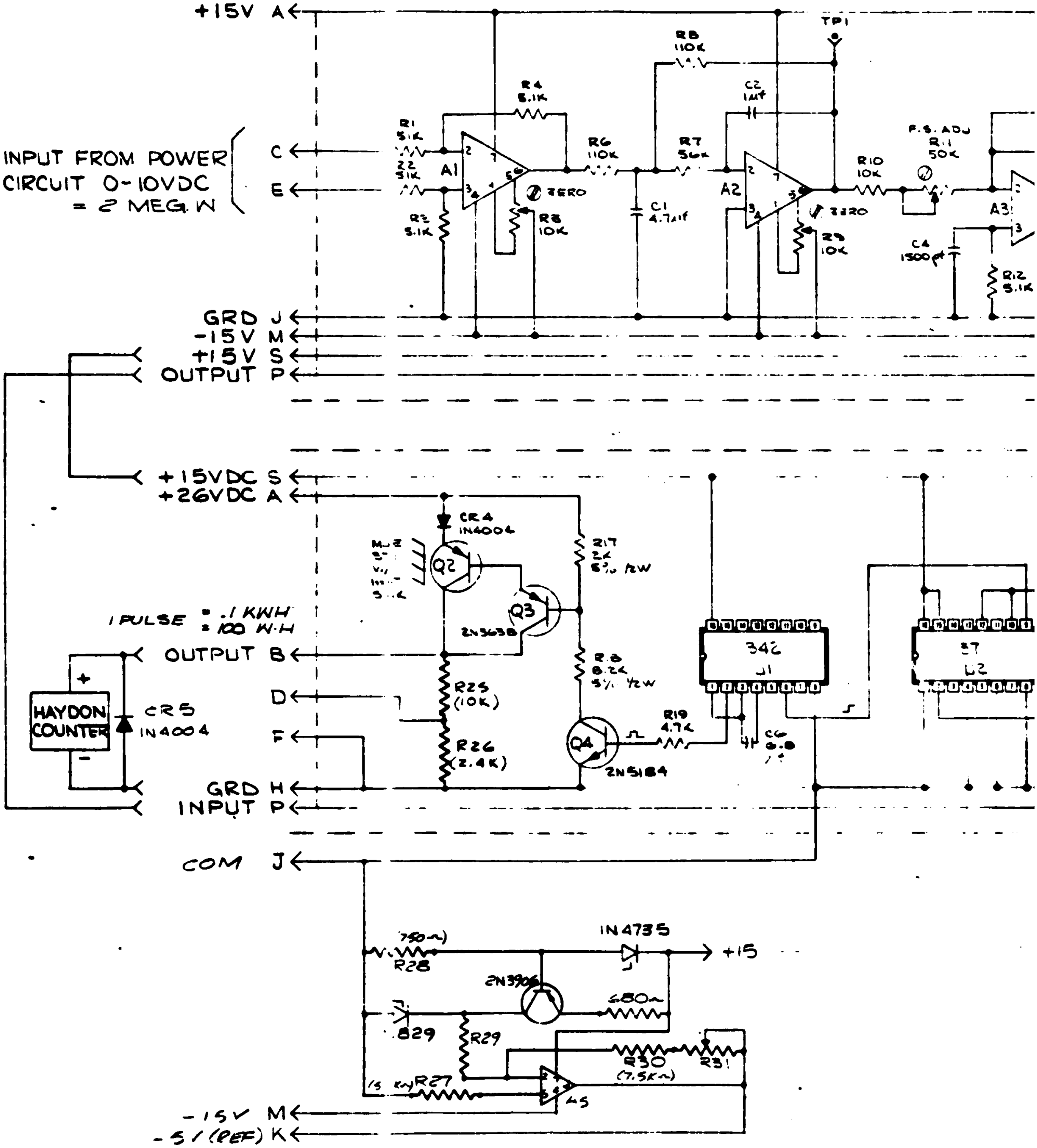
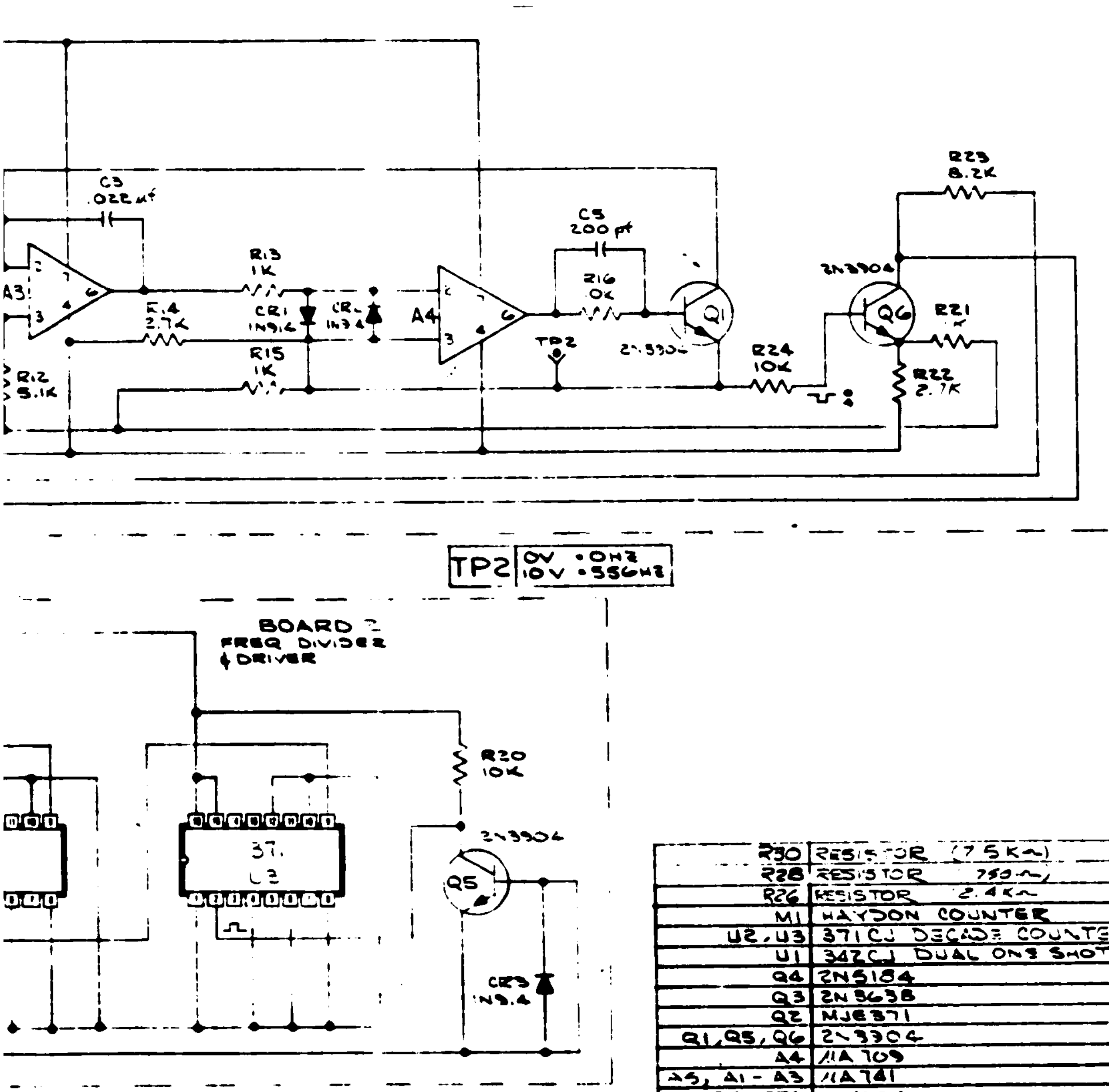


Figure 2–10. DC Kilowatt Hour Meter Schematic



R30	RESISTOR (7.5K~)
R28	RESISTOR 750~)
R26	RESISTOR 2.4K~
M1	HAYDON COUNTER
U2, U3	371CJ DECADE COUNTER IC
U1	342CJ DUAL ONE SHOT IC
Q4	2N5184
Q3	2N3638
Q2	MJE371
Q1, Q5, Q6	2N3904
A4	µA 709
A5, A1 - A3	µA741
CR5, CR4	1N4004
CR1, CR2, CR3	1N914
C6	6.8 uf
C5	200 pf
C4	1500 pf
C3	.022 uf
C2	1Mf
C1	47 Mf
R18	8.2K 5% ½ W
R17	2K 5% ½ W
R23	8.2K 2% METAL FILM RESISTOR
R19	4.7K
R.4, R2	2.7K
R31, R13, R15, R22	1K
R.1	30K
[illegible] R24	10K
R7	56K
R6, R8	110K
R27, R3, R4, R12	5.1K
R, R5	51K 2% METAL FILM RESISTOR

t = time in seconds

$$W = \frac{Pt}{3600} = 0.0002777\ Pt$$

$$F_0 t = 0.002777\ Pt$$

Equation 4

$$W = 0.1\ F_0 t$$

The counter display would, according to Equation 4, read directly in Kilowatt-hours, with a resolution of 0.1 kwh. The overall accuracy of this system is $\pm 2\%$ of full scale.

The three kilowatt-hour computer cards are numbered as follows: The analog multiplier is card 312, connected to jack J312. The DC-to-frequency converter is labeled KWH. It is not connected to the rear patch panel. The frequency divider and power driver card is labeled 317, and is connected to jack J317 for recording. J317C drives the impulse counter.

Brake pressure is measured by a strain gage pressure transducer. Signal conditioning for this parameter is shown in Figure 2-6. The card is identical to the cards in the Structural Behavior Signal Conditioning panel. The outputs of all cards are on their correspondingly numbered jacks on the rear patch panel.

2.3 DESCRIPTION OF OTHER SYSTEM COMPONENTS

2.3.1 Playback Signal Conditioner

The Playback Signal Conditioner, shown in Figure 2-11 comprises a voice amplifier, a tone decoder, and a frequency-to-DC verter. During the recording of test data, it is used to con- record event marks and one wheel speed on the oscillographs in tape delayed time. The unit is also used during playback of recorded data at the test track for a quick look at the results. This type of quick look analysis is useful to verify that the data acquisition system is functioning properly.

The Playback Signal Conditioner has two data inputs and three outputs. The two inputs are taken from the voice channel and one of the wheel speed channels on the tape recorders. The three outputs are a voice signal which drives a speaker, an event pulse derived from the decoded event tone recorded on the voice channel, and a DC analog of one wheel speed. The latter two outputs are recorded on the oscillographs.

2.3.2 Event Marker and Voice Amplifier

This unit, shown in Figure 2-12 enables a voice commentary and events mark to be added on a single edge track of two separate tape recorders. The realization of these two functions is described in the following paragraphs.

A Turner microphone with push-to-talk switch is employed to record voice. The Sangamo tape recorders have a voice annotate feature which will allow voice to be recorded regardless of whether the machine is in the record mode or not. The push to talk switch must key on the bias oscillator in both tape recorders. This is accomplished by grounding Pin B of J1. Diodes CR3 and CR4 are used to isolate the power supplies of the two tape machines. The voice output from the microphone is fed to a summing amplifier Z3 and then to the tape recorder edge tracks. The input impedance of Z3 matches that of the tape recorder, and with its gain of one, Z3 presents the same load on the microphone as the tape recorder would.

The event marker is a hand-held switch on the end of a retractile cord. This is used to fix in time the starting points of various tests. To avoid wasting a data channel of the tape recorder, the event mark is recorded on top of the voice edge track as a one-second tone burst of approximately one kHz. The frequency is generated by a Wien bridge oscillator. Pushing the event marker button grounds pin D of J1 and the following occurs (see Figure 2-12):

1. Pin B is grounded through CR1, keying on the bias oscillators in both tape recorders.

2. Q3, which had been held on by R11, is now turned off. Pin 5 of the one-shot, Z4, is now pulled up by R3. This triggers the one-shot on for one second.

3. The one-shot, Z4, does several things. It turns on Q6 and Q5, which apply 15 volts to the divider networks, R16 to R19, providing a DC level shift to place the event mark on the oscillographs. When Q5 is on, it also turns on Q7 and Q8, which hold the pin B of J1 at ground. This keeps the bias oscillators in the tape recorders on for the duration of the event mark. Z4 also turns on Q4 which gates on Z1, a programmable op-amp. Z2 feeds the one kHz tone into the summing junction of Z3, which in turn drives the tape recorder edge tracks.

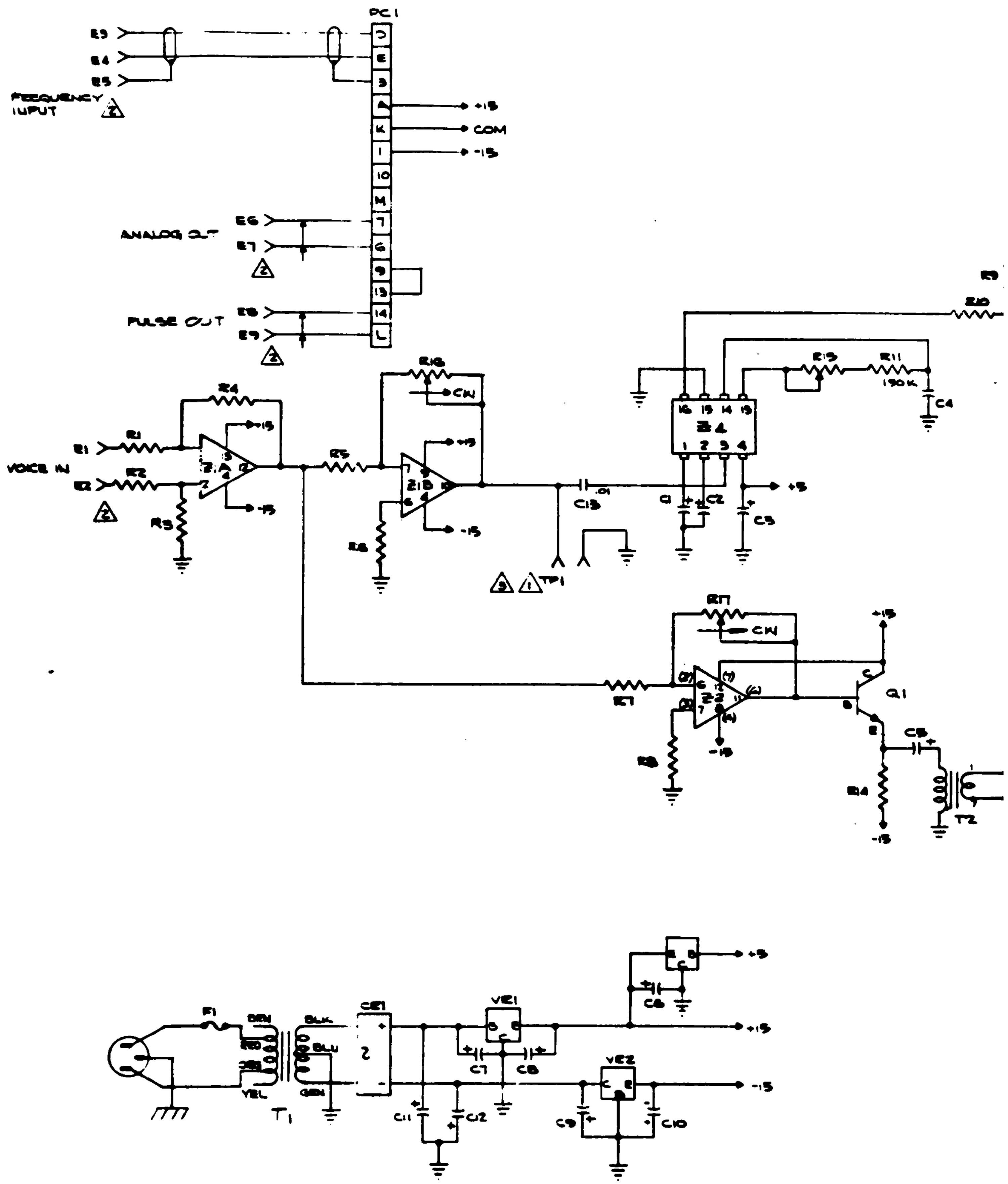
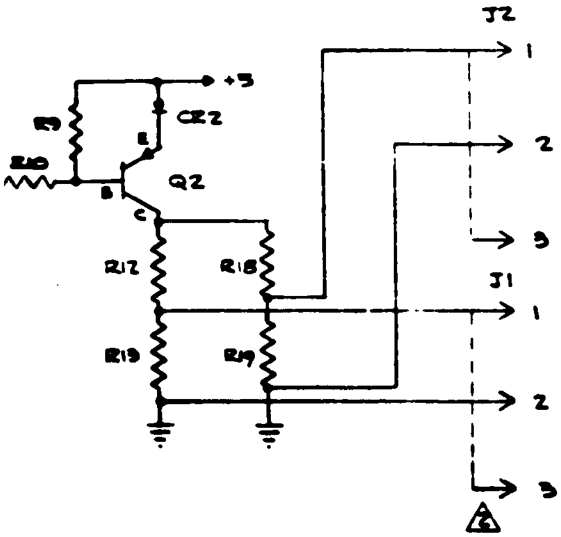
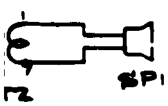


Figure 2–11. Playback Signal Conditioner Schematic





	35	Z_1	U7A7747-312	DUAL OP-AMP
	34	PC1	LSK 36282	TACH
	33	Z4	NE 567V	TONE DECODER, SIGNETICS
	32	Z2	U5B7741-393	OP-AMP FAIRCHILD
	31	VR3	LM309H	REGULATOR NAT. SEMI
	30	VR2	LM120K-15	REGULATOR NAT SEMI
	29	VR1	UGJ7815393	REGULATOR NAT SEMI
	28	T2	A-3837	TRANSFORMER STANCOR
	27	T1	21F101	TRANSFORMER THORDARSON
	26	SP1	27A063.2	SPEAKER, QUAM
	25	R17		RESISTOR 50K Ω VOLUME CONTROL
	24	R16	3059J-1-503M	TRIMPOT BOURNS
	23	R15	50-3 2-102	TRIMPOT SPECTROL 1K
	22	R14	500 Ω	RESISTOR 5W WIRE WOUND
	21	R13,R19	RL07	RESISTOR 200 Ω 1/4W 2%
	20	R12,R18		43K Ω
	19	R11		1.5K
	18	R10		510 Ω
	17	R6,R8		22K
	16	R1-R5,R7	RL07	RESISTOR 20K Ω 1/4W 2%
	15	Q2	2N3638A	TRANSISTOR
	14	Q1	2N3185	TRANSISTOR
	13	J1-J2	XLR3-32	CONNECTOR CANNON
	12	F1	1/2 AMP	FUSE
	11	E1-E9	2142	MINIATURE BANANA JACK, POMONA
	10	CR2	IN4002	DIODE
	9	CR1	MDA 920A	DIODE, BRIDGE MOTOROLA
	8	C13	.01 μf	CAPACITOR
	7	C11,C12	500 μf	CAPACITOR, ELECTROLYTIC
	6	C7,C9	2.2 μf	CAPACITOR, TANTALUM
	5	C5	68 μf	
	4	C4	47 μf	
	3	C3,C8	3.3 μf	
	2	C2	2.2 μf	
	1	C1	68 μf	CAPACITOR, TANTALUM

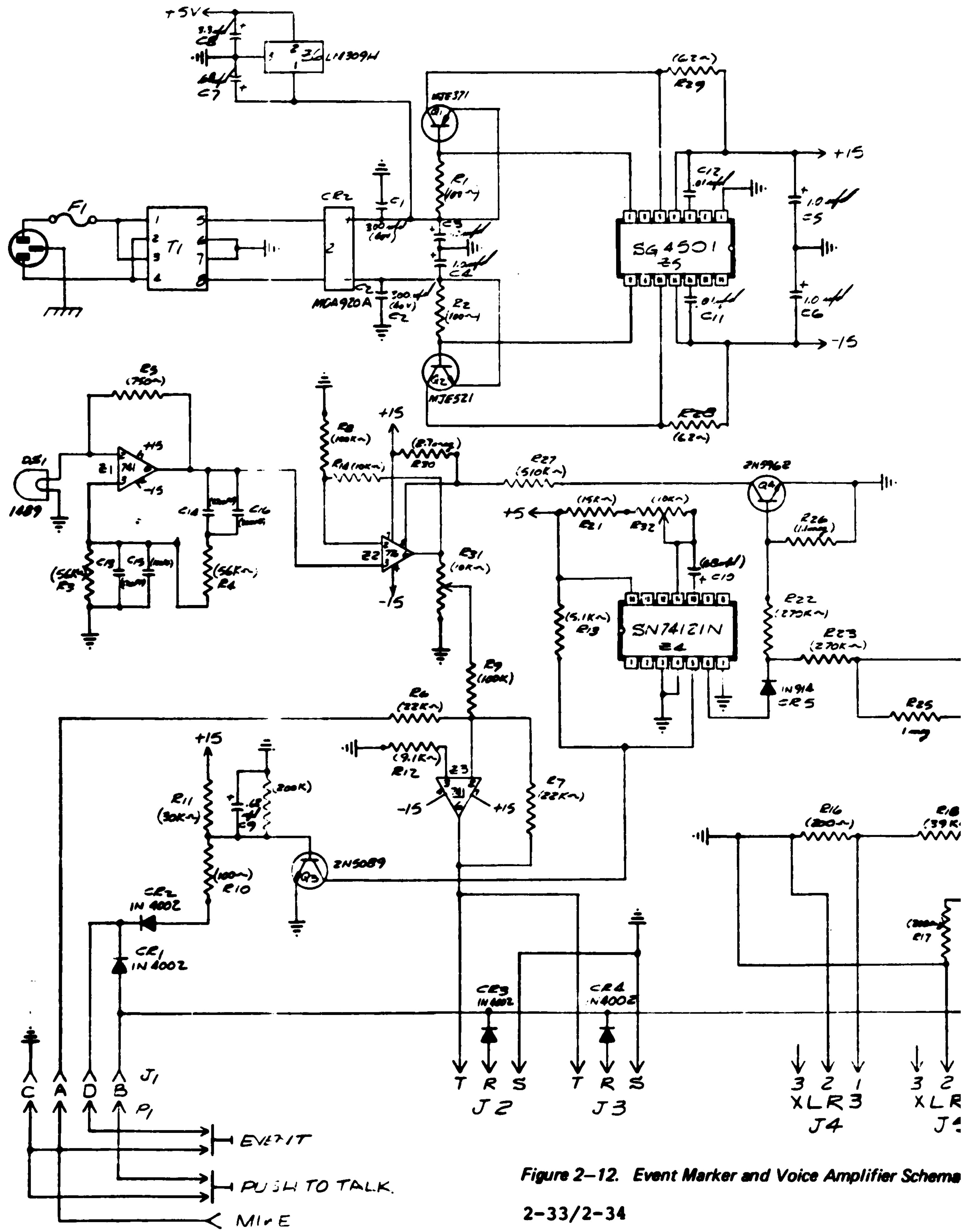
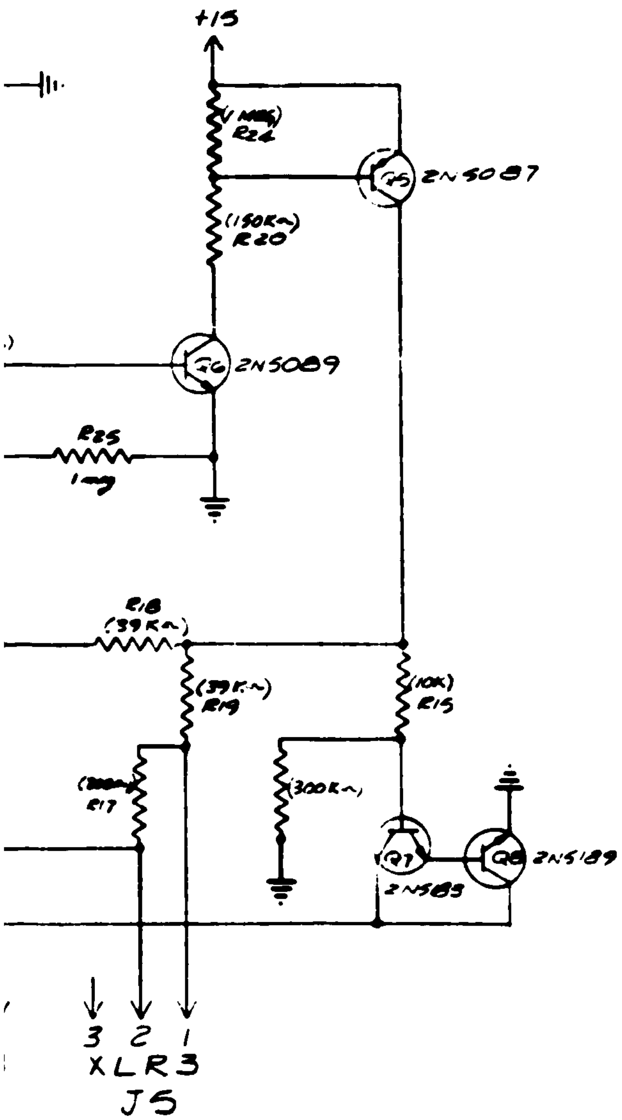


Figure 2–12. Event Marker and Voice Amplifier Schema



lifier Schematic

Z6	LM309H	VOLT REGU.	NAT'L SEMICONDUCTOR	
Z5	SG45C1	VOLT REGU.	SILICON GENERAL	
Z4	SN74121N	MONOSTABLE IC	TEXAS INSTRU.	
Z2	U5B7776-393	OP AMP		FAIRCHILD
Z1, Z3	U5B7741-393	OP AMP		FAIRCHILD
T1	FR 34-170	TRANSFORMER		
R31, R32	3339P-1-103	TRIMPOT (10KΩ)		BOURNS
R30	2.7 MEG	RESISTOR	1/4W, 5%	CARBON
R28, R29	6.2Ω			
R27	510KΩ			
R26	1.1 MEG			
R24, R25	1 MEG			
R22, R23	270KΩ	RESISTOR	1/4W, 5%	CARBON
R21	15KΩ	RESISTOR	1/4W, 2%	RL07
R20	150KΩ			
R18, R19	39KΩ			
R16, R17	200Ω			
R14, R15	10KΩ			
R13	5.1KΩ			
R12	9.1KΩ			
R11	30KΩ			
R8, R9	100KΩ			
R6, R7	22KΩ			
R5	750Ω			
R3, R4	56KΩ			
R1, R2, R10	100Ω	RESISTOR	1/4W, 2%	RL07
Q8	2N5189	TRANSISTOR		
Q7	2N5183			
Q5	2N5087			
Q4	2N5962			
Q3, Q6	2N5089			
Q2	MJE521			MOTOROLA
Q1	MJE371	TRANSISTOR		MOTOROLA
P1	PT06A-8-4P(SR)	CONNECTOR		BENDIX CONN
DS1	1489	LAMP		
J4, J5	XLR3-32	CONNECTOR		CANNON CONN
J2, J3	MT332-B	PHONE JACK		TRIMM
J1	PT00A-8-4S	CONNECTOR		BENDIX CONN.
F1	MDL-1	FUSE		
CR6	MDA920A-7	BRIDGE RECTIFIER		
CR5	1N914	DIODE		
CR1-CR4	1N4002	DIODE		
C15, C16	100 PF	CAPACITOR, MICA		
C13, C14	2700 PF		MICA	
C11, C12	3D6E153		ELPAC MYLAR	
C10	6652MC		TANTALUM	(68 μf) KEMET
C8	150D			(33 μf) SPRAGUE
C7, C9	150D			(.68 μf)
C3-C6	150D			(... μf)
C1, C2	601D	[illegible], TANTALUM		[illegible]

Section 3

CALIBRATION PROCEDURES AND EQUIPMENT

3.1 SOAC CALIBRATOR

3.1.1 Description and Theory of Operation

The SOAC Calibrator shown in Figure 2-1 was designed to provide an accurate and rapid calibration of all signal conditioning circuitry used in the SOAC Instrumentation package. The Calibrator derives its operating power from the conditioner being checked. Power is brought in on pins 1, 2 and 3 (plus, common and minus; and on 73 and 74, input from the constant current source when checking resistance transducers (current source on card 201 to 214).

The output is switched to the signal carrying pins of the conditioners. Refer to the table under general theory of operation for the signal conditions.

The Calibrator provides DC voltages from zero to ten volts, in ten millivolt steps. Zero to ten volts negative is also available in ten millivolt steps. In the frequency position of the function switch, an internal Wien bridge oscillator generates a pure sine wave of variable frequency and amplitude. The frequency is in two ranges, and is adjustable from less than 100 Hz to over 6000 Hz. The amplitude is adjusted with the voltage step selector. The voltage dial reads in peak volts in the frequency mode.

The resistance calibration is a precision variable resistor, calibrated in one ohm step. When switched to the resistance function, a constant current of five milliamps is fed in on pins 73 and 74. This current is applied to the precision resistor and the resulting voltage sent back to the amplifier being tested. For example, with five milliamps and 100 ohms, the resulting voltage will be $(5 \times 10^{-3})\ 100 = 0.5$ volts. With 500 ohms the output voltage will be $(5 \times 10^{-3})\ 500 = 2.5$ volts.

Refer to Figure 2-1. The precision DC voltage is generated by applying a constant current source (CR1, R2, Q1) to a reference Zener diode (CR2). The voltage developed across CR2 is stable to $\pm 0.0005\%$ per degree centigrade. This voltage is nominally 6.2 volts. Amplifier Z1A, a non inverting amplifier, boosts this reference voltage to precisely ten volts. Inverting amplifier Z1B has a gain of exactly minus one, its output being minus ten volts.

Z3A, and its associated components form a Wien bridge oscillator. Z3B amplifies this signal to exactly 10 volts peak. The plus 10 volt reference voltage, the minus reference voltage, and the 10 volt peak AC voltage are all routed through S1, which in turn applies them to the input resistor of Z2.

The input resistor of Z2 has a value of 10 kilohms, $\pm 0.5\%$. The feedback resistor of Z2 is a decade resistor, calibrated in kilohms. With ten volts input to Z2, the value of all reference voltages, and the dial set to 10.00 kilohms the output is ten volts, the gain being exactly unity. When the dial is set for 4.73 kilohms the output of Z2 becomes 0.473 (10 volts), equal to 4.73 volts. Therefore, the dial reads directly in volts. The minimum step is 10 millivolts.

3.2 INITIAL SET-UP AND CALIBRATION PROCEDURE

3.2.1 Equipment Required

- Plus and minus fifteen volt power supply, 1/2% regulation or better.
- Digital Voltmeter, 0.01% accuracy or better.

3.2.2 Procedure

Unless stated otherwise, all readings are with respect to common. Refer to Figure 2-1. Slide the front panel out after removing the panel screws and the cable clamp screws on the bottom of the cabinet. Connect plus 15 volts to pin 1, common to pin 2 and minus 15 volts to pin 3 of P1. Connect a jumper wire across CR2, and adjust R11 for zero (± 0.001) on pin 12 of Z1A. Remove the jumper and adjust R14 on the rear of cabinet for + 10.000 volts on pin 12 of Z1A. Adjust R12 for minus 10.000 volts on Pin 10 of Z1B. Set the function switch at the "EXT" input position and the voltage dial at zero. Adjust R13 for Zero volts on the output monitor jacks. Switch the function selector to the frequency position, and the voltage dial to 10 volts. Adjust R15 for 7.07 volts RMS on the output monitor jacks. This completes the calibration procedure. Replace the cable clamp screws and the front panel.

3.3 RIDE QUALITY SIGNAL CONDITIONER CALIBRATION PROCEDURE

Refer to Figure 2-3 which pertains to Cards 101 to 122.

These cards are buffer amplifiers with zero offset and gain adjustment. The zero can be offset plus or minus 5 volts and the gain can be varied from less than one to more than four. Input impedance is essentially infinite and the output impedance is less than 75 ohms.

No initial calibration is required on these cards.

3.3.1 Periodic Calibration

To calibrate cards 101 to 112 plug the SOAC calibrator into J123. Select channel 1 for card 101 and select the function of + voltage. Set the output voltage for zero. Adjust the "offset" trimpot on the card edge for zero, or any desired zero offset. Set the Calibrator for 1.000 volts out and adjust the "gain" trimpot for the desired span.

To calibrate channels 113 to 122 plug the Calibrator into J124. Repeat the procedure of the previous paragraph.

3.4 STRUCTURAL BEHAVIOR SIGNAL CONDITIONER CALIBRATION PROCEDURE

This unit has three kinds of Signal Conditioning Cards. Procedures for these three types are presented below. Refer to the master wiring diagrams, Figure 2-4, for card and socket numbering and other necessary information.

3.4.1 Displacement Conditioning Card

Refer to Figure 2-5 which pertains to Cards 201 to 214.

3.4.1.1 Initial Set-up

Equipment required

- SOAC Calibrator
- Digital Voltmeter (FLUKE 8000A or Equivalent)

Procedure

Remove power by unplugging unit. Plug the Calibrator into J225. Plug the digital voltmeter (DVM) into the excitation test jack on the rear of the conditioner. Set the Calibrator function to resistance. Set the dial to zero ohms. Set the pot current test switch to "202" and the Calibrator to channel 2-14. Remove cards 201 through 214 from the unit.

Apply power and plug card 201 into slot 202. Adjust the "current adj" trimpot on the card edge until the DVM reads 100.0 millivolts. This sets the constant current source for 5 milliamps of excitation current. Remove card 201 and plug in card 202. Adjust the current pot on 202 for 100.0 millivolts on the DVM. Repeat for all cards (201 to 214). Replace all cards in their respective slots.

3.4.1.2 <u>Periodic Calibration</u>

Plug the Calibrator into J225, connect the DVM to J201, place the Calibrator in the resistance mode, and the channel selector in the number 1 position. Set the resistance dials for 0000. Adjust the offset pot, on the edge of card 201 for - 5.00 volts output. Move the resistance dials to 1,000 ohms and adjust the gain pot, on the edge of card 201, for + 5.00 volts output. Check linearity by adjusting the setting in 100 ohm steps as shown below in Table 3-1.

TABLE 3-1. STANDARD CALIBRATION OF DISPLACEMENT SIGNAL CONDITIONING CARD

Ohms	Output Volts
0000	-5.00
0100	-4.00
0200	-3.00
0300	-2.00
0400	-1.00
0500	0.00
0600	+1.00
0700	+2.00
0800	+3.00
0900	+4.00
1000	+5.00

Plug the DVM into J202, switch the Calibrator to channel 2 and repeat the calibration procedure for card 202. Adjust the offset pot at zero ohms for -5.00 volts output and adjust the gain pot for +5.00 volts output with 1000 ohms input.

Repeat for 203, 204, etc., through 212.

To calibrate channels 213 and 214 plug the Calibrator into J226. Set the pot current test switch to "214." Plug card 213 into slot 214 and proceed as before. Repeat for card 214.

3.4.2 Strain Gage Amplifier, DC Coupled

Refer to Figure 2-6 which pertains to cards 221 to 224 and 318.

3.4.2.1 Initial Set-Up

Connect a 350 ohm dummy bridge to the input pins of strain channel on J226, (refer to Figure 2-4). Temporarily remove the excitation pins. Connect the DVM between common and pin 6 of Z1 (see Figure 2-6) and adjust R6 for zero volts dc. Rotate R4 fully CW, at least five full turns, then rotate R4 two turns CCW. Connect an oscillator between the excitation pins of the dummy bridge and common. Set the oscillator for one volt RMS at 500 Hz. Rotate R5 for minimum ac output on pin 6 of Z1. Remove the oscillator. Adjust R7 for zero on pin 6 of Z2. In a like manner, adjust R8 for zero on pin 6 of Z3.

Select R balance. Start with 75,000 ohms. If the balance pot is too sensitive increase the value of the balance resistor. If the bridge will not balance, decrease the value of the balance resistor.

The "R cal" resistor value is obtained from the transducer manufacturer's data sheet, by dead weighting the transducer or by calculation from the gauge factor.

This completes the initial calibration. This need not be repeated unless components on the board are replaced.

3.4.2.2 Periodic Calibration

With the transducer connected and unloaded, switch in the "R cal" resistor and check for output voltage on the rear patch panel or on the card edge test points.

3.4.3 Strain Gage Amplifier, AC Coupled

Refer to Figure 3-1 which pertains to Cards 215 to 220. The procedure for initial calibration is identical to the procedure for the DC coupled amplifier, (Figure 2-6).

Identified on the schematic is the coupling plug which selects ac or dc coupling. The plug must be in the DC position (direct coupled) for all calibration procedure.

3.4.3.1 Periodic Calibration

This card monitors dynamic loads superimposed on a variable static load. Therefore, the balance point for various car loads will shift. The AC coupling will ignore these static loads and respond only to the dynamic condition. The amplifier should be approximately balanced with a balance resistor and balance pot and then left in that position.

3.5 PERFORMANCE SIGNAL CONDITIONER CALIBRATION PROCEDURE

Refer to Figure 2-7.

Equipment Required

- Digital voltmeter, Fluke 8000A or equivalent.
- Frequency counter, H.P. 5300A or equivalent.
- SOAC Calibrator, LSK 36285
- Oscilloscope

Procedures

No initial calibration is required on Cards 301 through 311.

3.5.1 Card 301, Periodic Calibration

Plug the SOAC Calibrator into J319. Set the function for plus volts and the channel selector for channel 1-13. Set the output voltage to zero and adjust the offset pot on the card edge for zero volts on J301 and the rear patch panel. Set the Calibrator to +5 volts and adjust the gain pot on the card edge for +5 volts out. Recheck the zero and test at several points to confirm linearity.

3.5.2 Card 302, Periodic Calibration

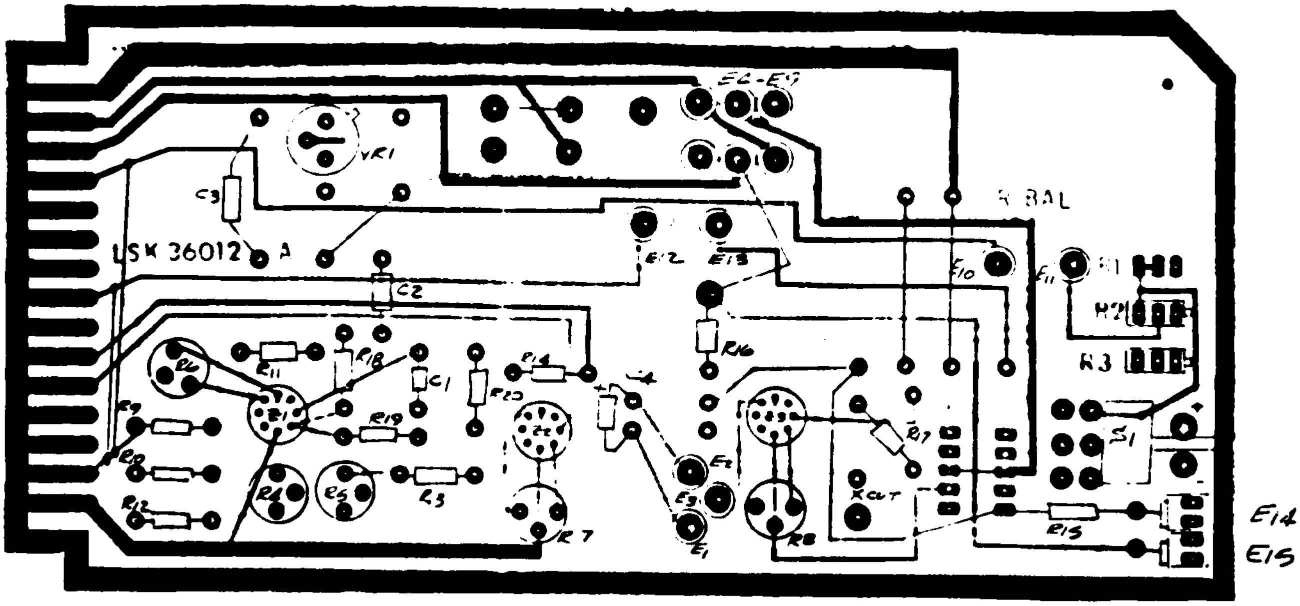
Switch the Calibrator to channel 2-14 and set the Calibrator to zero volts. Adjust the offset pot on card edge for minus five volts. Set the Calibrator for +5 volts and adjust the gain pot for +5 volts out on J302. Recheck zero and full scale.

Cards 303 through 311 are calibrated in a like manner. A tabulation of inputs and outputs is shown in Table 3-2.

3.5.3 Card 312, Power Computer

3.5.3.1 Initial Calibration

Place card 312 on a card extender. Remove card 302, 303, KWH and 317 from their sockets. Refer to Figure 2-9 for the following adjustments. Remove the multiplier (A1) from its socket. Adjust R13 for zero volts on pin 6 of Z1. Adjust R14 for zero volts on pin 6 of Z2. Adjust R15 for zero on pin 6



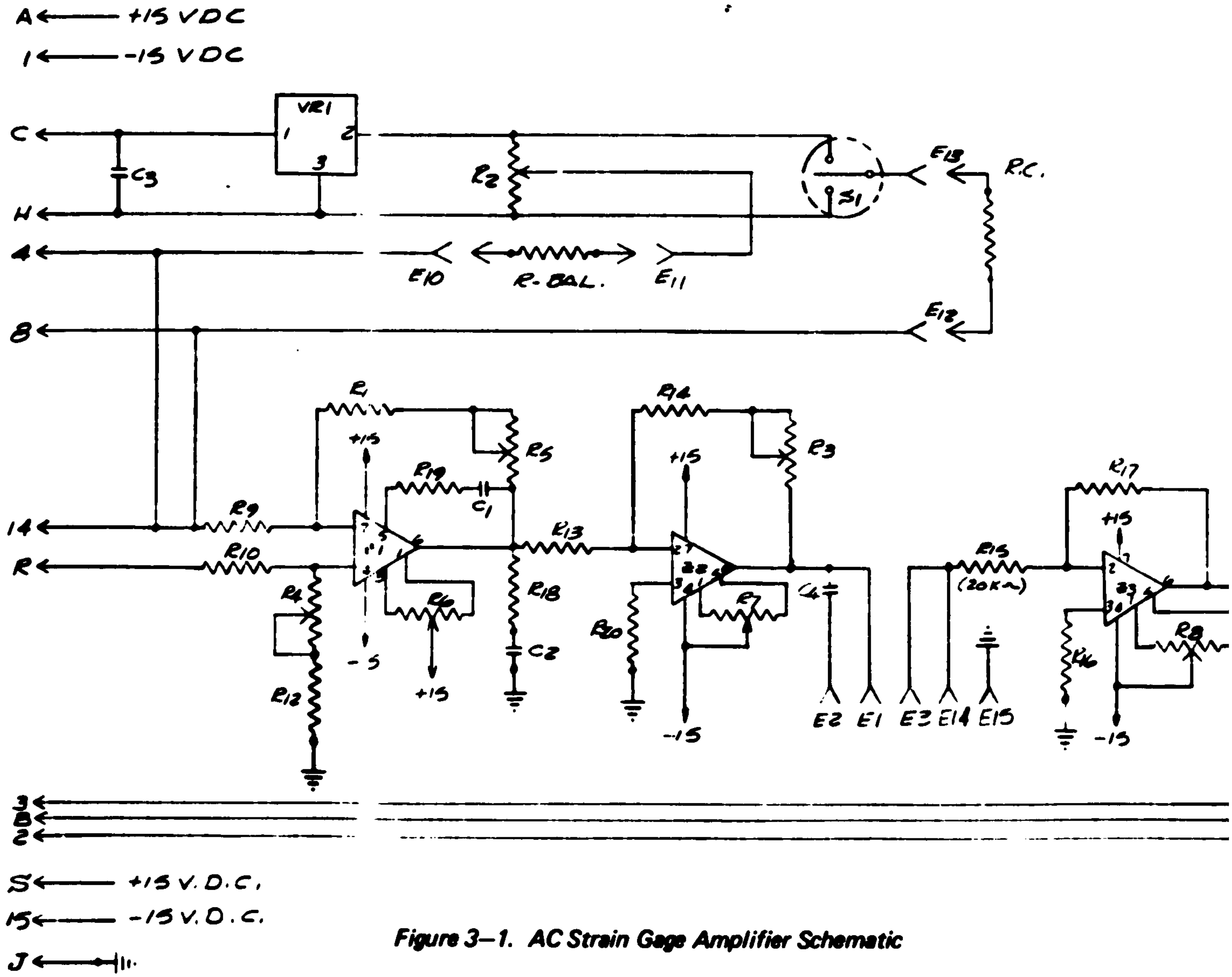
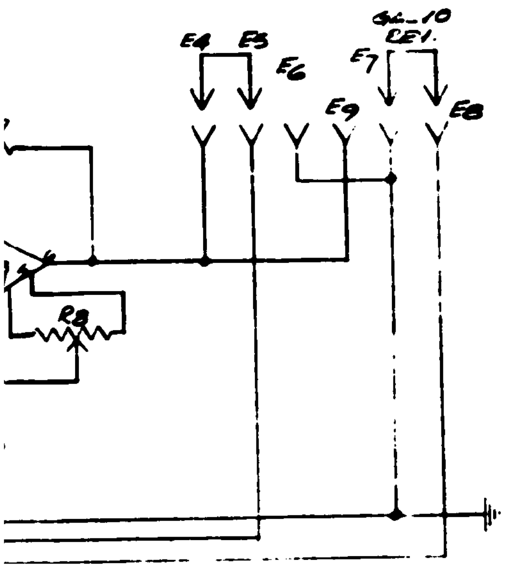


Figure 3–1. AC Strain Gage Amplifier Schematic



Z2-Z3	U5B7741-312	OP. AMP			FAIRCHILD
Z1	U5T7725-312	OP. AMP.			FAIRCHILD
VR1	LM 309H	REGULATOR			
S1	T02-221	SWITCH		J.B.T.	
R20	RL07	RESISTOR	(680Ω)	1/4W, 2%	
R19	RL07		(270Ω)		
R18	RL07		(27Ω)		
R17	RL07		(200KΩ)		
R16	RL07		(18KΩ)		
R15	RL07		(20KΩ)	1/4W, 2%	
R14	5-180		(500Ω)	1/8W, 1/2%	JORDAN
R13	5-180		(1KΩ)		
R11-R12	5-180		(1megΩ)		
R9-R10	5-180	RESISTOR	(100KΩ)	1/8W, 1/2%	JORDAN
R7-R8	3339P-1-103	TRIMPOT	(10KΩ)		BOURNS
R6	3399P-1-104	TRIMPOT	(100KΩ)		BOURNS
R4-R5	3339P-1-203	TRIMPOT	(20KΩ)		BOURNS
R2-R3	3299-1-103	TRIMPOT	(10KΩ)		BOURNS
E1-E9	3388-1-03	TEST JACK			CAMBION
E14-E19	3422-1-03	TEST JACK			CAMBION
E10-E13	3397-2-03	COMPONENT JACK			CAMBION
C4	3.3 mfd	CAPACITOR			TANTALUM
C3	.68 mfd	CAPACITOR			TANTALUM
C1	1XGR152	CAPACITOR			[illegible]
C2	2C2K473	[illegible]			[illegible]

TABLE 3-2. STANDARD CALIBRATIONS OF PERFORMANCE SIGNAL CONDITIONING CARDS

Card Number	Calibrator Channel	Parameter Range Zero	Parameter Range to Full Scale	Input Zero	Input Range Full Scale	Output Range Zero	Output Range to Full Scale	Output Connector
301	1-13	0	±0.25 g	0	±5 volts	0	±5 volts	J301
302	2-14	0	±5 volts	0	+5 volts	-5	+5 volts	J302
303	3-15	0	+2000 amperes	0	+5 volts	-5	+5 volts	J303
304	4-16	0	+1000 volts	0	+5 volts	-5	+5 volts	J304
305	5-17	0	+1000 amperes	0	+5 volts	-5	+5 volts	J305
306	6-18	0	±50 amperes	0	±5 volts	0	±5 volts	J306
307	7-19	0	+1000 volts	0	+5 volts	-5	+5 volts	J307
308	8-20	0	+1000 amperes	0	+5 volts	-5	+5 volts	J308
309	9-21	0	±50 amperes	0	±5 volts	0	±5 volts	J309
310	10-22	0	+1 ampere	0	+5 volts	-5	+5 volts	J310
311	11-23	0	+5 amperes	0	+5 volts	-5	+5 volts	J311

of Z3. Replace A1 in its socket. Now adjust R16 for zero on Pin 6 of Z3. Remove 312 from the extender. Place card 317 on the extender in slot 317. Adjust R31 for -5.000 volts on pin 6 of A5. Remove card 317. Place card KWH on the extender and in its respective slot. Adjust R5 for zero on pin 6 of A1 and R9 for zero on pin 6 of A2.

Place cards 312, 302 and 317 in their slots. Set the Calibrator to channel 1-13 and set the voltage to +5 volts on the Calibrator. Make certain that exactly +5 volts is on J302 and that card 303 is not in its socket. Parallel J302 and J303 and adjust R31 on LSK 36076 for 10 volts on J312.

Check linearity according to the input and output values listed in Table 3-3. Reset the Calibrator to +5 volts. On Card KWH, the DC-to-frequency converter shown in Figure 2-10 measure the frequency of the pulses on the emitter of Q1 (i.e., at the test point labeled TP2). Adjust R11 for exactly 556 Hz.

The adjustment and calibration of the kilowatt-hour computer is now complete. The scale factors are as follows: 0-10 volts dc corresponds to 0-2 Megawatts on J312, one pulse equals 100 watt-hours on J317.

TABLE 3-3. STANDARD CALIBRATION VALUES FOR POWER COMPUTATION CARD

Calibrator Setting (Volts DC)	Output of J312 (Volts DC)
5.00	10.00
4.00	8.10
3.00	6.40
2.00	4.90
1.00	3.60
0.00	2.50
-1.00	1.60
-2.00	0.90
-3.00	0.40
-4.00	0.10
-5.00	0.00

3.5.4 Cards 313 through 316, Wheel Speed

3.5.4.1 Initial Calibration Procedure

Plug the Calibrator into J320, set the function for frequency, and the voltage dial for 0.000. Place card 316 on the extender and in its slot. Refer to Figure 3-2. Set the calibrator for

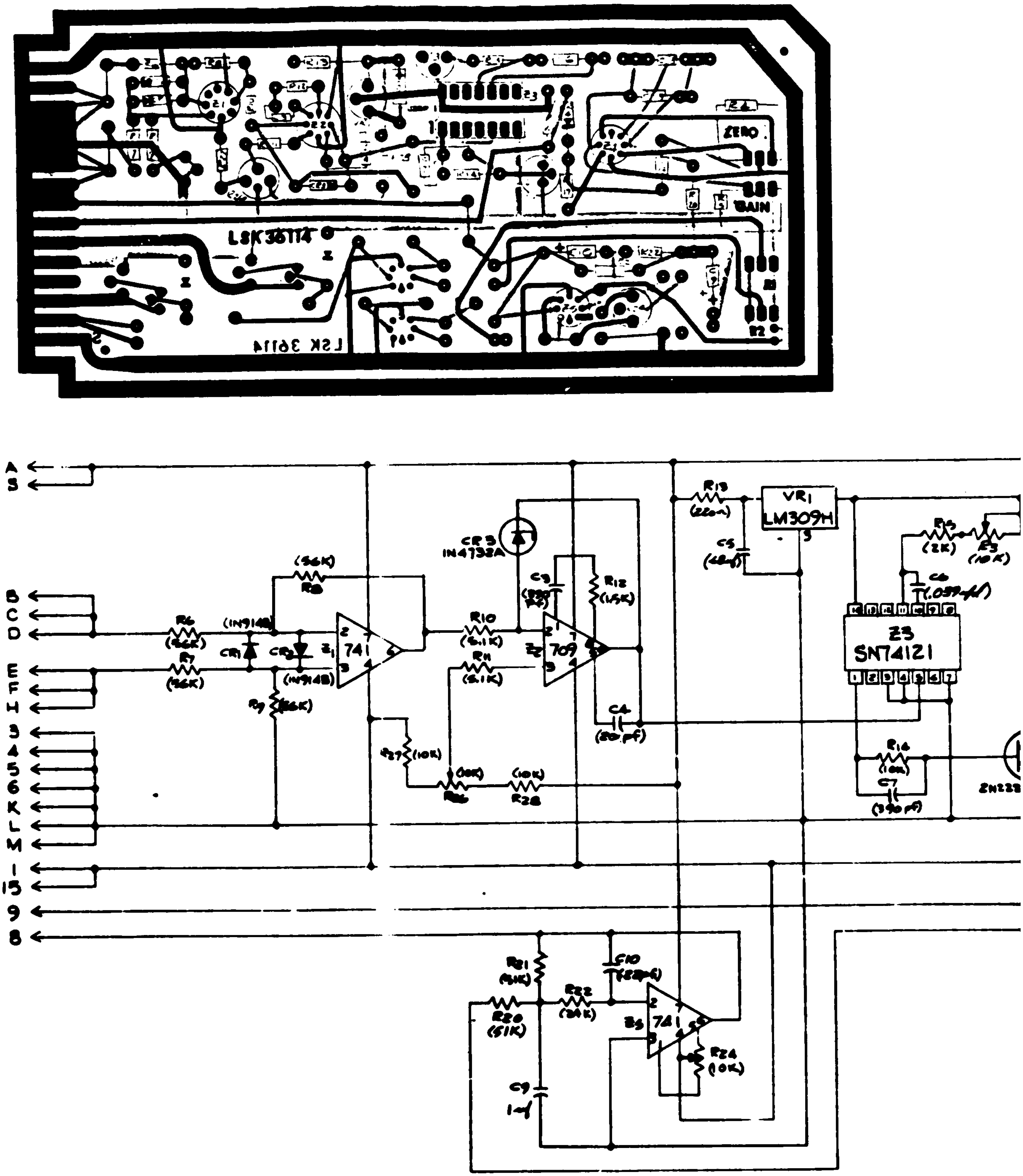
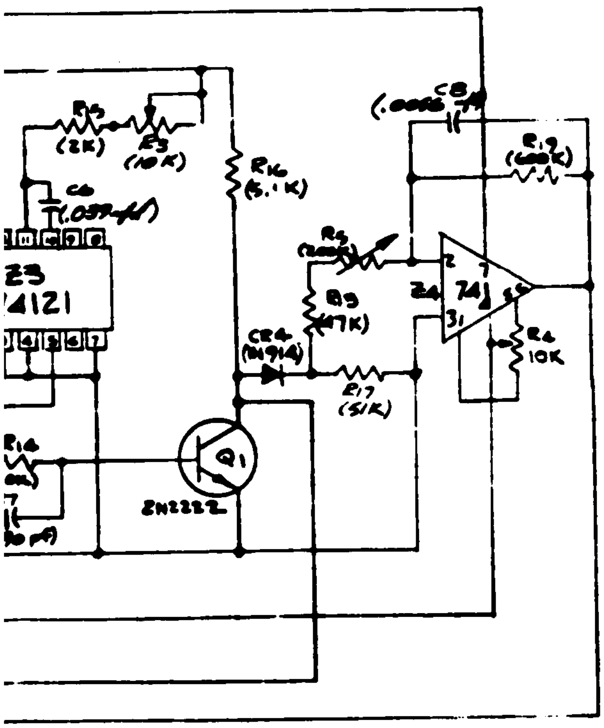


Figure 3–2. Frequency-to-DC Converter Schematic



Q1	TRANSISTOR (2N2222)		
Z3	T.I.	(SN74121N)	
Z2	OP. AMP	(FUSB770939)	
Z1, Z4, Z5	OP. AMP	(FUSB7741393)	
C10		(.22 μf)	SPRAGUE
C9		(1 μf)	SPRAGUE
C8		(.0056 μf)	ERAC
C3, C7		(390 pf)	
C5		(.68 μf) 150D	SPRAGUE
C4		(20 pf)	
C6		(.039 μf)	ERAC
CR1, CR2, CR4	DIODE	IN914B	
CR3	DIODE	IN4732A	
R19	RESISTOR	600K	JORDAN 5-160
R32	RESISTOR	22 MEG, 1/4W, 5%	
R13	RESISTOR	220 Ω, 1/2W,	
R22	RESISTOR	24K, 1/4W, 2%	
R18		47K	
R15		2K	
R12		1.5K	
R10, R11, R6, R7, R8		5.1K	
R17, R20, R21		51K	
R14	RESISTOR	10K, 1/4W, 2%	
R6 - R9	RESISTOR	56K, 1/4W, 2%	
R5	TRIMPOT	(P/N3282W-1-204)	BOURNS 200K
R4	TRIMPOT	(P/N3299X-1-103)	BOURNS 10K
R3, R26, R36	TRIMPOT	(P/N3329-P-1-103)	BOURNS 10K
LSK 36-14	P.C. BOARD		

channel 1-13 and the voltage output for 1.000 volt. Adjust R26 for a symmetrical square wave on pin 5 of Z3. Plug the counter into the monitor jacks on the calibrator and adjust the frequency control to 2510 Hz. Adjust R3 for a square wave with a 30 percent duty cycle at J313P. (Note: Cards X1 to X4 must be in the X4 position.)

3.5.4.2 Periodic Calibration

With the same connection as above, set the calibrator at 0.000 volts out and adjust pot R24 (see Figure 3-2) for zero volts on Pin 6 of Z4 and adjust R4 for zero on J313. Set the voltage for 1.000 peak and the frequency for 2510 Hz. Adjust the gain pot R5 for a 2-inch deflection on the galvanometer. Scale factor now equals 40 mi/hr/inch. Repeat for Cards 314, 315 and 316.

3.5.5 Card 318, Brake Pressure

Calibration of card 318 is identical to cards 221 to 224, covered in Section 3.4.2.

3.6 PLAYBACK SIGNAL CONDITIONER CALIBRATION PROCEDURE (Figure 2-11)

Measure the frequency of the event marker tone burst generated by the event marker (LSK 36288). Measure this on pin 6 of Z1 and record this frequency. Connect an oscillator to the voice input jacks. Set the oscillator to the same frequency as measured on the Event Marker. Set the amplitude of the oscillator for 200 mv rms as measured on the test jacks. Measure the voltage from the collector of Q2 to common. This voltage will be either 5 volts DC or 0 volts dc if Z1 is tuned to the proper frequency. To tune Z1, monitor the voltage at the collector of Q1 and rotate CCW until a 5 volt reading is obtained; continue rotating until Q1 falls to zero. Rotate R15 CW until 5 volts is again obtained. Continue to rotate R15 CW slowly. Count the turns required to cause Q1 to fall to zero. Rotate R15 back one-half this number in a CCW direction.

Connect the playback conditioner to the tape recorder, connect an oscilloscope to the test jacks on the front panel. Start the recorder and push the event market button. Observe the one-second tone burst (1 kHz) and adjust pot R16 for 200 millivolts RMS (0.56 V P-P) tone burst amplitude. The collector of Q2 should be at 5 volts whenever a tone burst is present.

3.7 VOICE AMPLIFIER AND EVENT MARKER CALIBRATION PROCEDURE (Figure 2-12)

Connect an oscilloscope to the T (tip) of J2, connect a jumper between +5 volts and the junctions of R22, R23 and CR5. This will hold the event on. Adjust R31 for 400 millvolts RMS (1.1 volts P-P).

Remove the jumper, connect the scope to the collector of Q5. Push the event market button and observe the pulse on the scope. The pulse should be 15 volts in amplitude and one second duration. Adjust R32 if the length of the pulse is not one second.

Appendix A

SENSOR DESCRIPTIONS

Figures A-1 through A-14 of this appendix are diagrams of the sensing systems used to measure parameters of SOAC operating characteristics. Brief outline descriptions accompany these illustrations.

PARAMETER: CAR LONGITUDINAL ACCELERATION
(Figure A-1)

Measurement Method/Concept

Car acceleration is measured with a linear servo accelerometer.

Sensors

1.	Type	Schaevitz Engineering Model LSOC-0.25
2.	Quantity	1
3.	Range	±5.4 mph/second (±0.25g)
4.	Linearity	±0.02% full scale (best fit straight line)
5.	Hysteresis	Negligible
6.	Frequency Response	0-16 Hz
7.	Resolution	0.0001% full scale
8.	Calibration Accuracy	0.1%

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy, ±0.5%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

- Primary — Precision wedge (output vs angle)
- Secondary — Voltage substitution

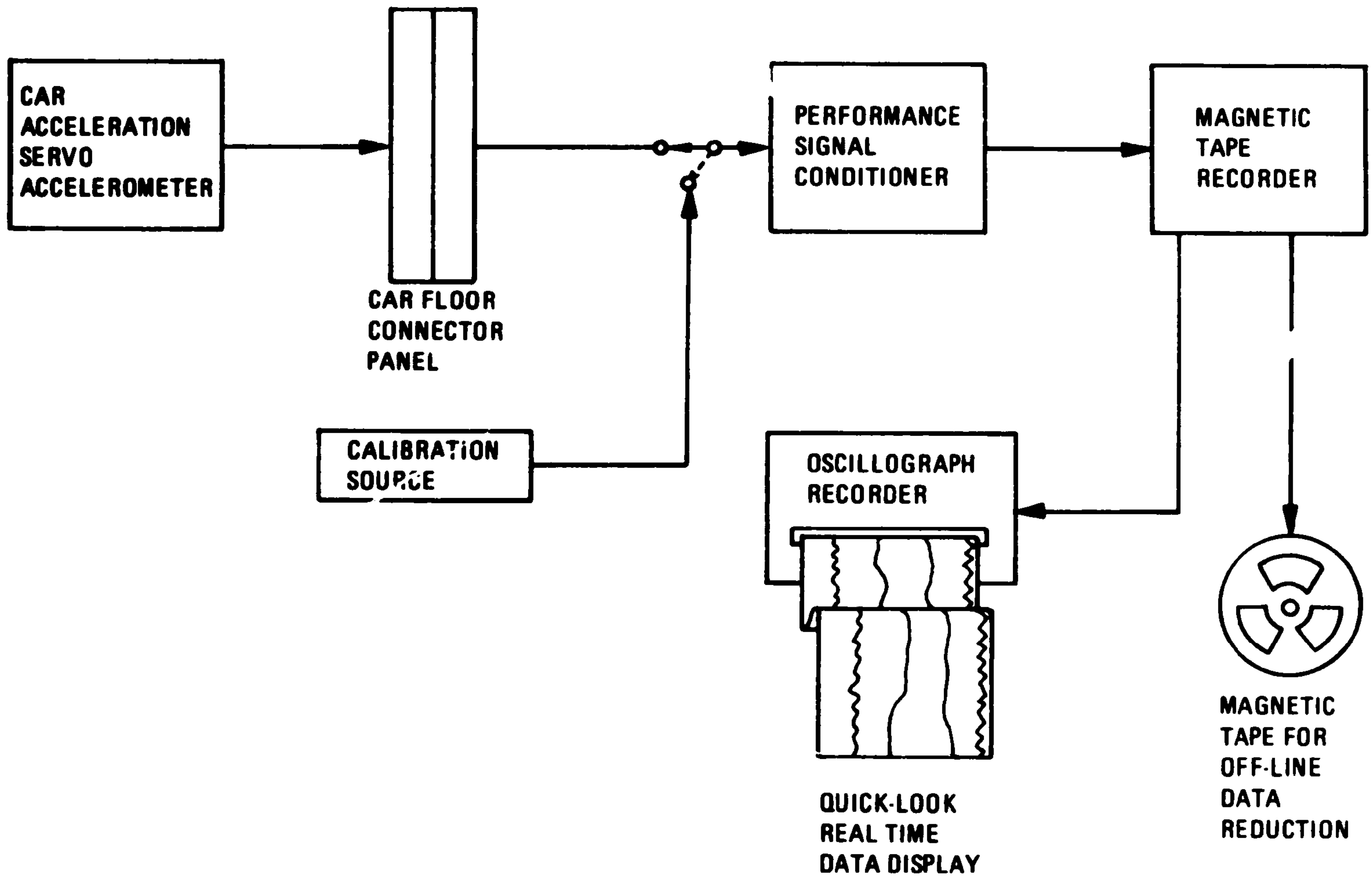


Figure A–1. Car Acceleration Measurement

PARAMETER: CAR SPEED
(Figure A-2)

Measurement Method/Concept

Speed is measured by a monopole pickup counting the number of teeth on a gear mounted on each traction motor shaft.

Sensors

1.	Type	Electro-Products Monopole pickup
2.	Quantity	4 (one per traction motor)

Signal Conditioning

- AiResearch design
- Provides buffering, offset and balance
- Overall accuracy:
  - (a) Frequency, ±1 count
  - (b) DC analog, ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Oscillator and crystal controlled time base frequency counter
• Secondary	Same as primary

Special Note

The speed measurement is based upon counting a 35-tooth gear mounted on each traction motor shaft and a traction motor speed of 4,300 rpm being equivalent to an 80 mph car speed.

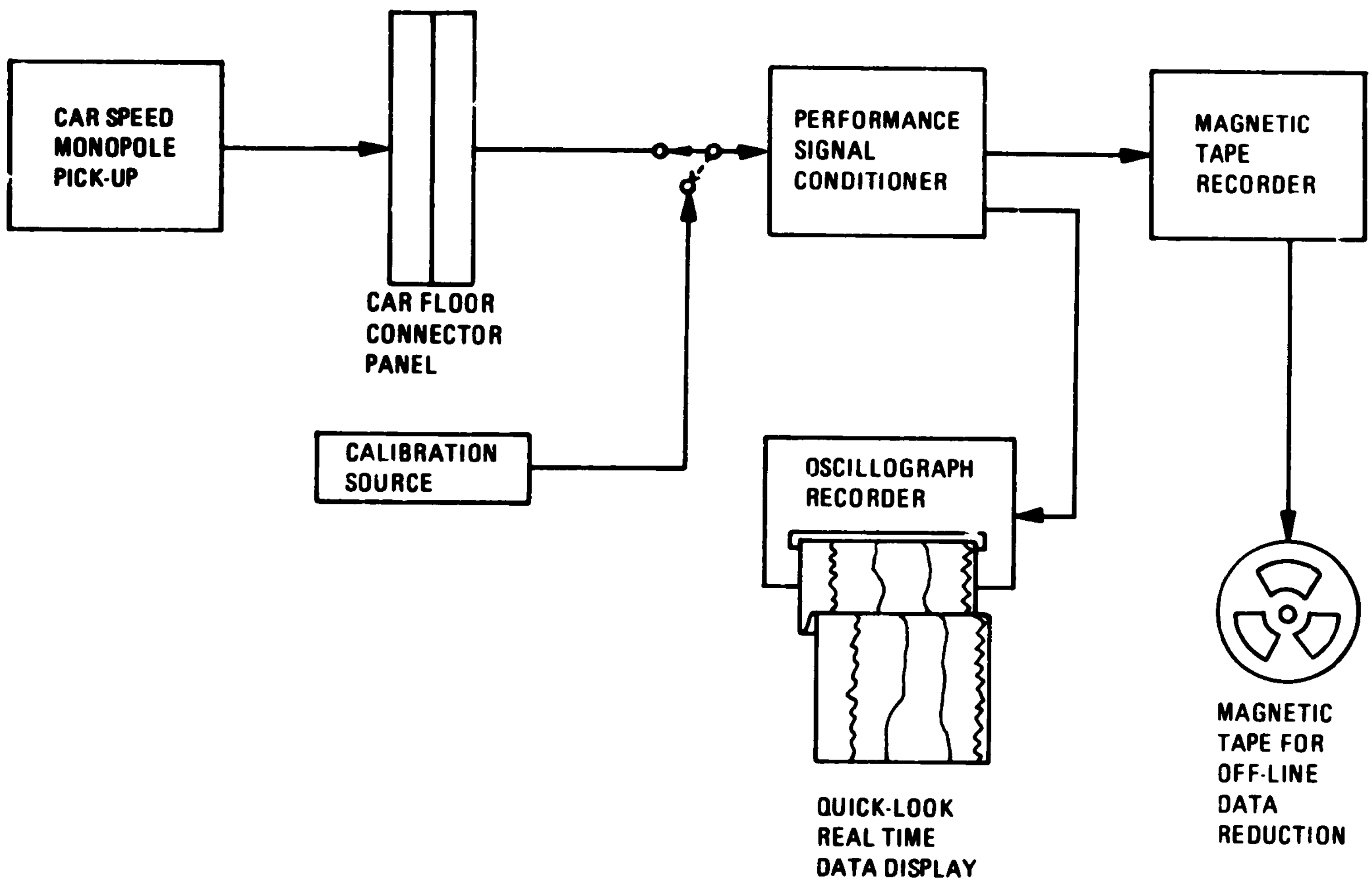


Figure A–2. Car Speed Measurement

PARAMETER: LINE VOLTAGE, TRACTION MOTOR VOLTAGE
(Figure A-3)

Measurement Method/Concept

Voltage is measured by precision resistive dividers.

Sensors

1. Type	AiResearch designed resistive divider
2. Quantity	5 (1 line voltage, 4 traction motor voltages)
3. Range	1000 VDC (1000 VDC in = 5VDC out)
4. Overall accuracy	±0.5%

Signal Conditioning

- AiResearch design
- Provides buffering, offset and balance
- Overall accuracy, ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	High voltage DC power supply and a precision digital voltmeter
• Secondary	Voltage substitution

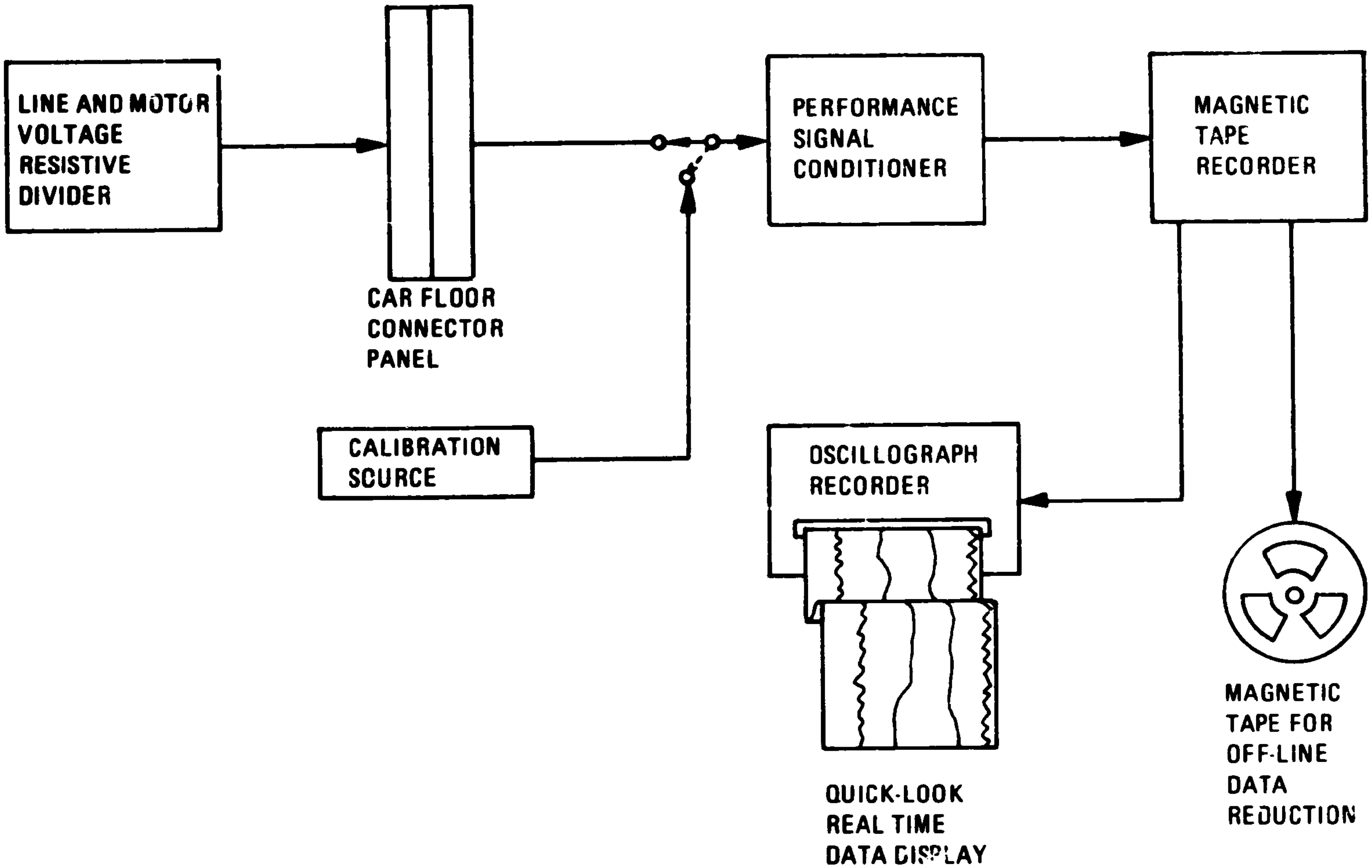


Figure A–3. Line and Traction Motor Voltage Measurement

PARAMETER: LINE CURRENT
(Figure A-4)

Measurement Method/Concept

Line current is measured with a Hall-effect type current sensor.

Sensors

1.	Type	AiResearch designed Hall effect current sensor
2.	Quantity	1
3.	Range	0-3000 amps DC
4.	Overall accuracy	±2.0%

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy, ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	High level DC current supply and current shunt
• Secondary	Voltage substitution

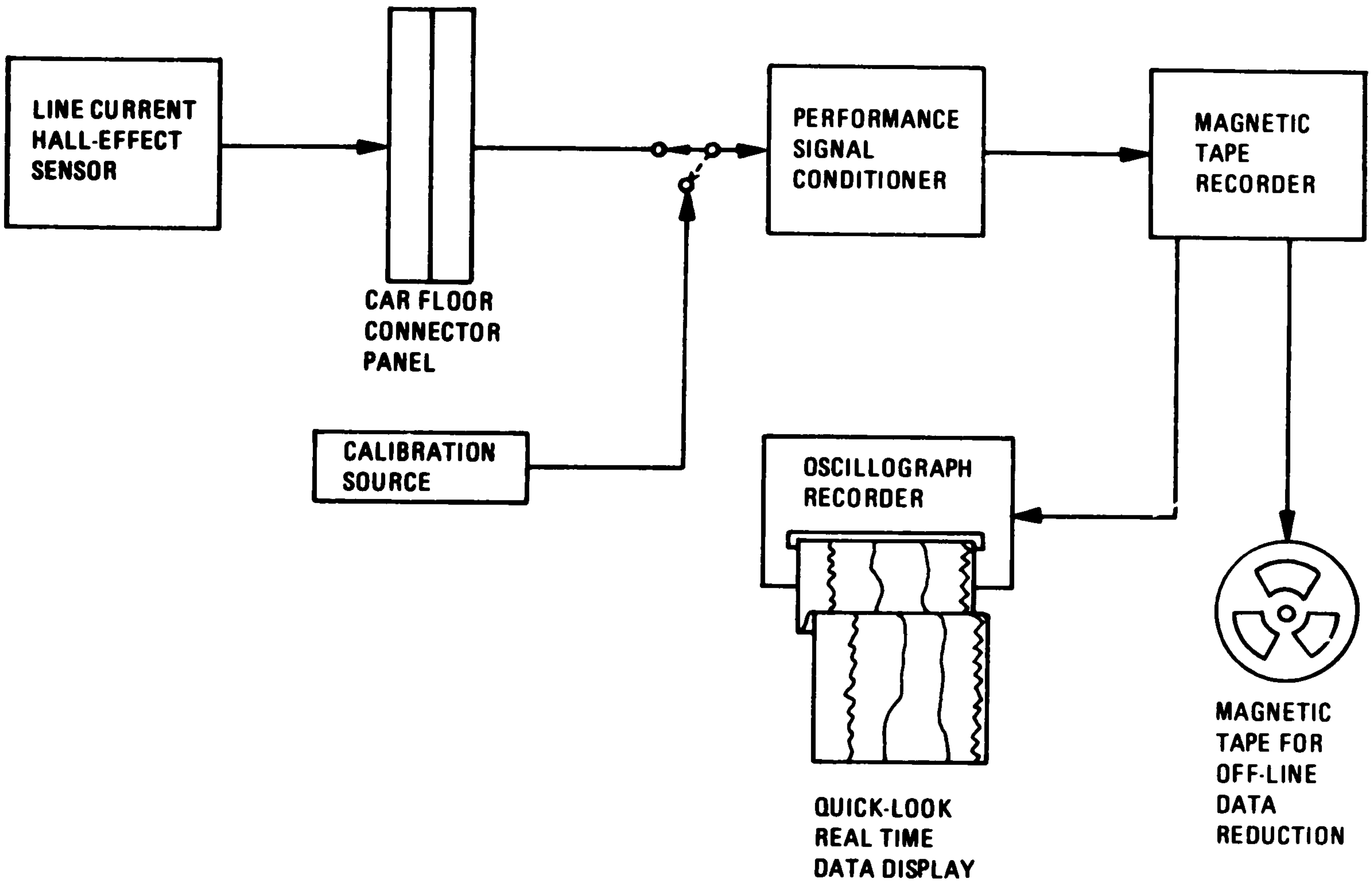


Figure A—4. Line Current Measurement

PARAMETER: TRACTION MOTOR CURRENT, TRACTION MOTOR FIELD CURRENT, "P" WIRE CURRENT, ANALOG VALVE CURRENT
(Figure A-5)

Measurement Method/Concept

Currents are measured with magnetoresistive sensors which sense the flux induced in lines due to current flowing in them.

Sensors

1.	Type	American Aerospace, Model 900
2.	Quantity	6 (2 traction motor currents, 2 traction motor field currents, 1 "P" signal current, 1 analog valve current)
3.	Range	± 1000 amps DC, traction motor current ± 150 amps DC, traction motor field current ±1 amp DC, "P" signal current ±5 amp DC, Analog valve current
4.	Overall accuracy	±2.0%

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	DC current supply and current shunt
• Secondary	Voltage substitution

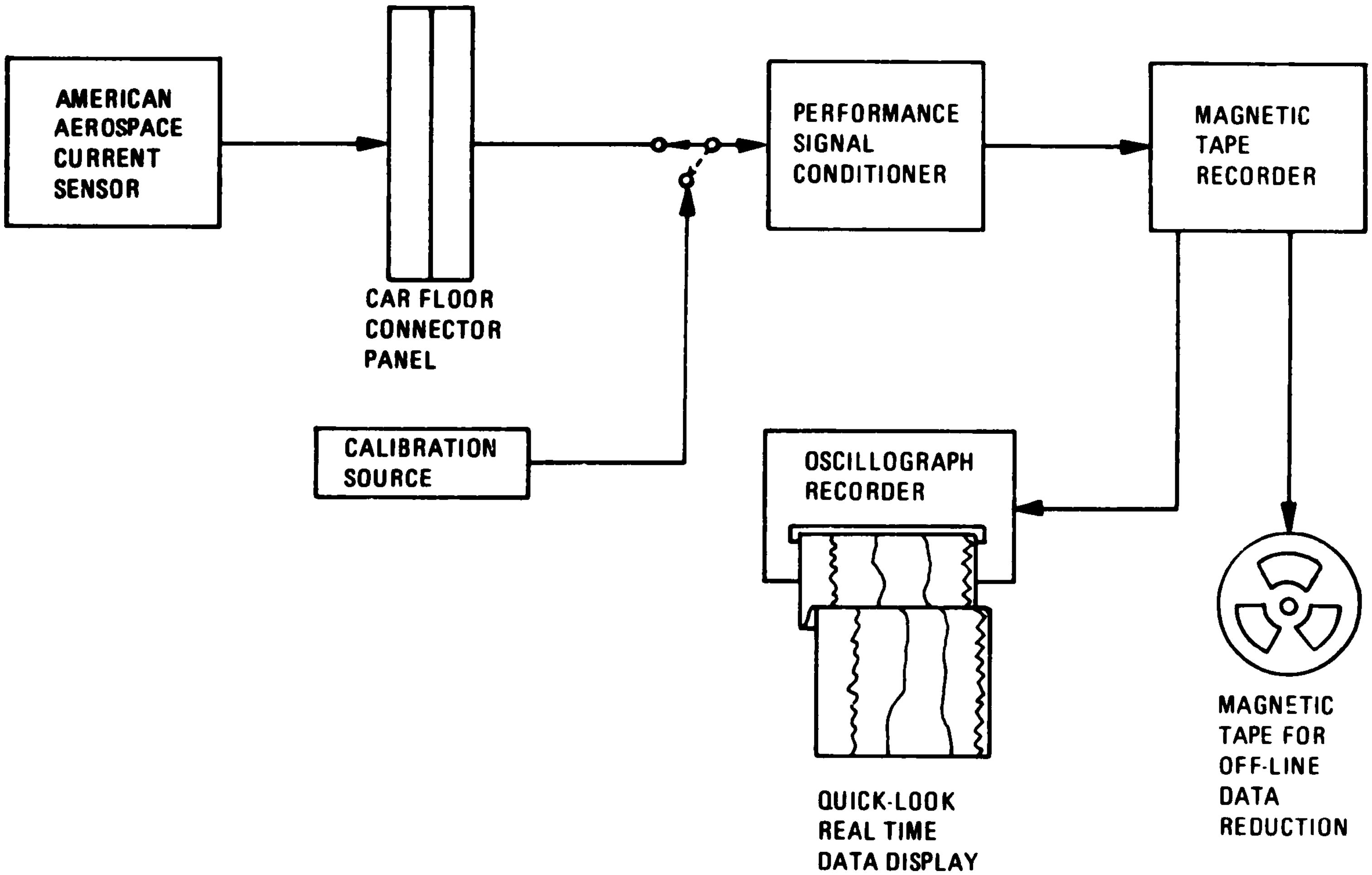


Figure A–5. Measurement of Traction Motor Current, Traction Motor Field Current, P-Wire Current, and Analog Valve Current

PARAMETER: BRAKE CYLINDER PRESSURE
(Figure A-6)

Measurement Method Concept

Pressure is measured with a strain gage type pressure transducer.

Sensors

1.	Type	Taber Instruments, Model 185
2.	Quantity	1
3.	Range	0-200 psig
4.	Linearity	$\pm$0.25% full scale (end point)
5.	Hysteresis	$< \pm$0.25% full scale
6.	Repeatability	$\pm$0.10% full scale

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, gain, offset and balance
- Overall accuracy $\pm$1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Dead weight pressure tester
• Secondary	Strain gage bridge unbalance using shunt resistance

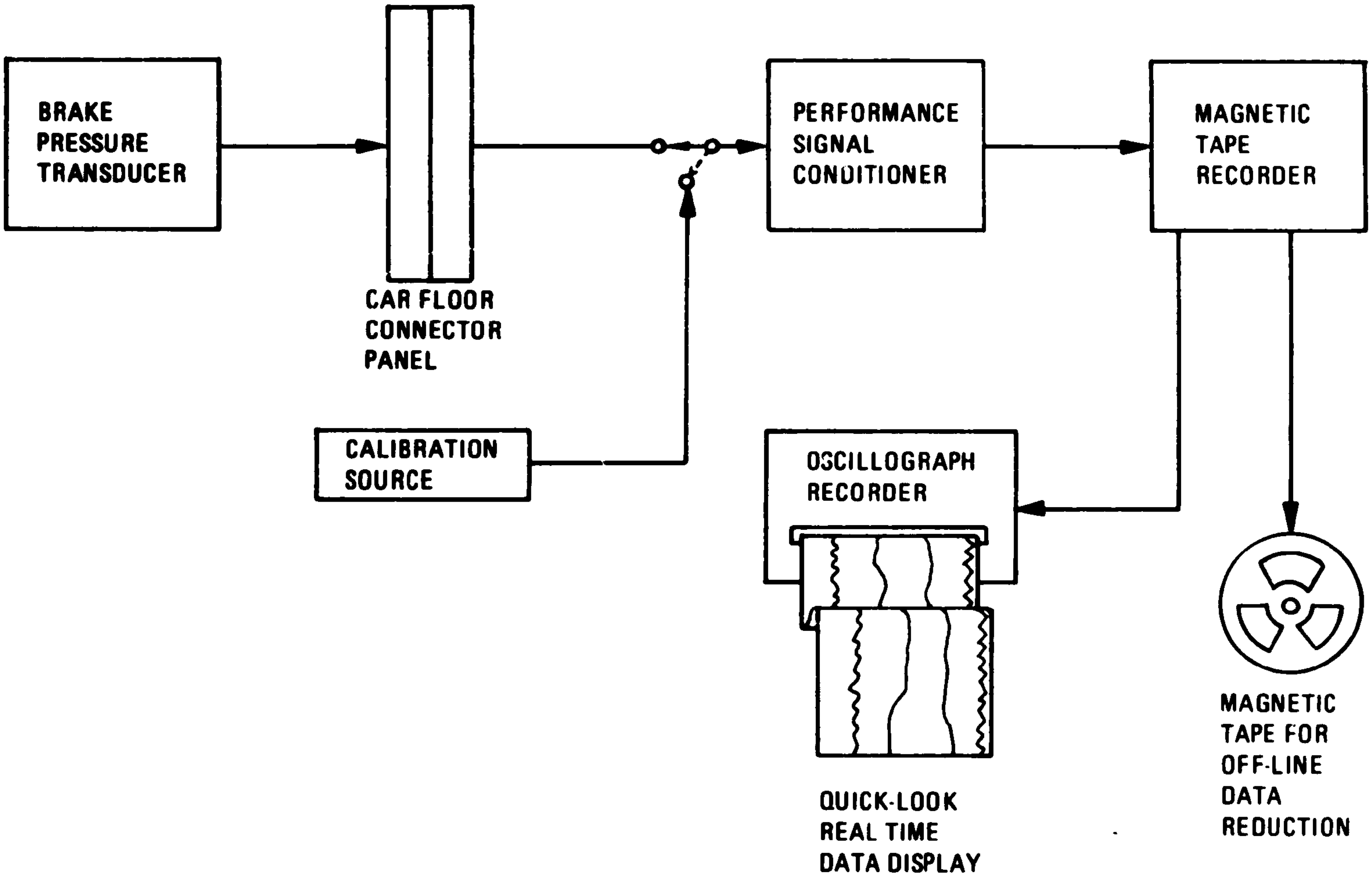


Figure A–6. Brake Cylinder Pressure Measurement

PARAMETER: KILOWATT-HOUR CONSUMPTION
(Figure A-7)

Measurement Method/Concept

Kilowatt-hour consumption is measured by multiplying the instantaneous values of current and voltage together.

Sensors

Not applicable

Signal Conditioning

- AiResearch design
- Provides multiplication of the output of line voltage and line current conditioning, buffering, offset and balance
- Overall accuracy, $\pm 5.0\%$

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder
- Real-time display on an electro-mechanical counter

Calibration

• Primary	Voltage and current sources, shunt, digital voltmeter, wattmeter, counter-timer
• Secondary	Voltage substitution and counter-timer

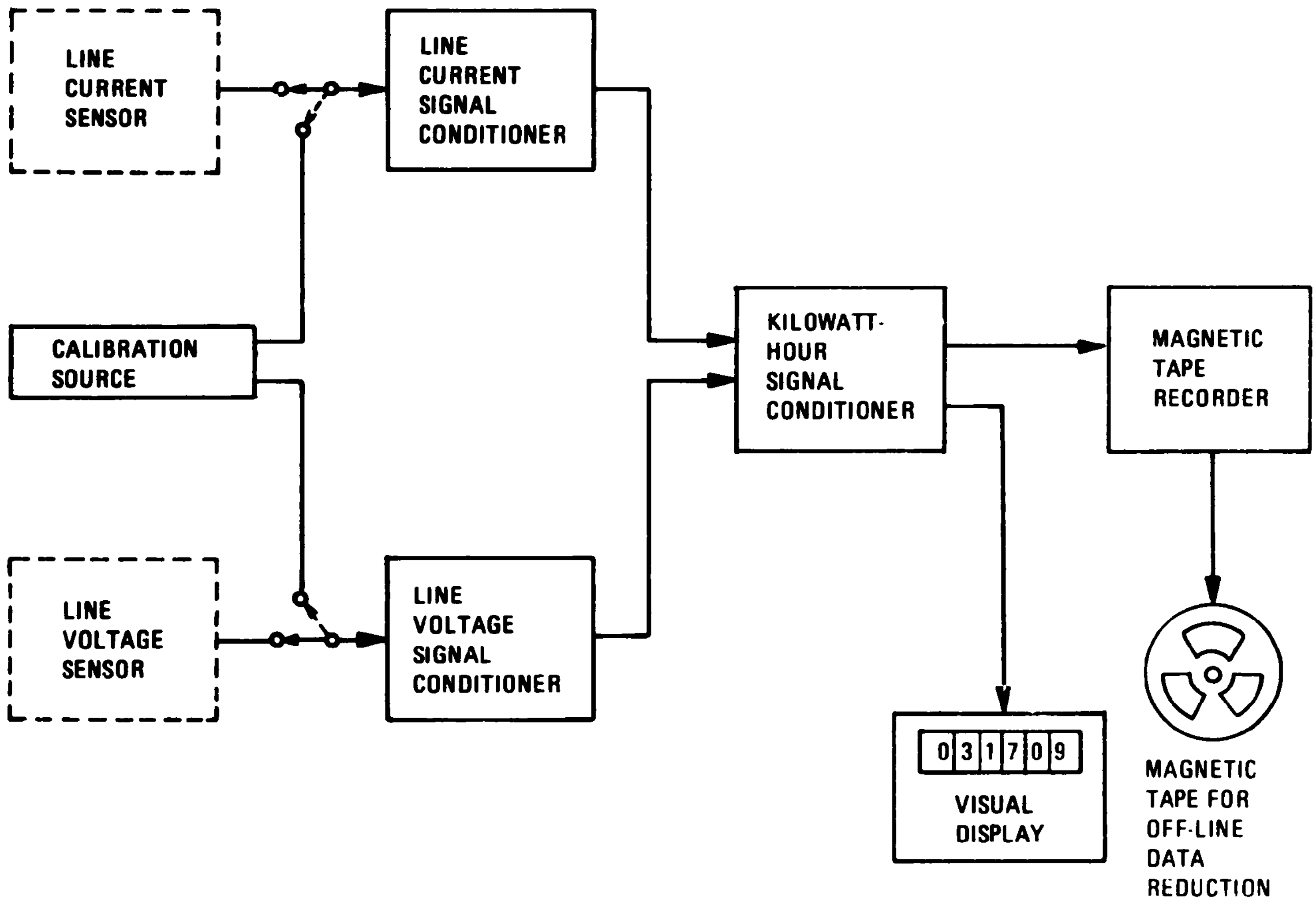


Figure A–7. Kilowatt-Hour Consumption Measurement

PARAMETER: EQUIPMENT TEMPERATURES
(Figure A-8)

Measurement Method/Concept

All temperatures are measured with thermocouples.

Sensors

1.	Type	Type K (Chromel-Alumel) thermocouples
2.	Range	Ambient-750°F
3.	Quantity	18
4.	Overall accuracy	±1.0%

Signal Conditioning

- Leeds and Northrup Speedomax H 12-channel recorder, range 0° to 800°F
- Overall accuracy, ±0.3% full scale

Recording Method

See signal conditioning

Calibration

• Primary	Precision voltage source and thermocouple reference tables
• Secondary	Same as primary

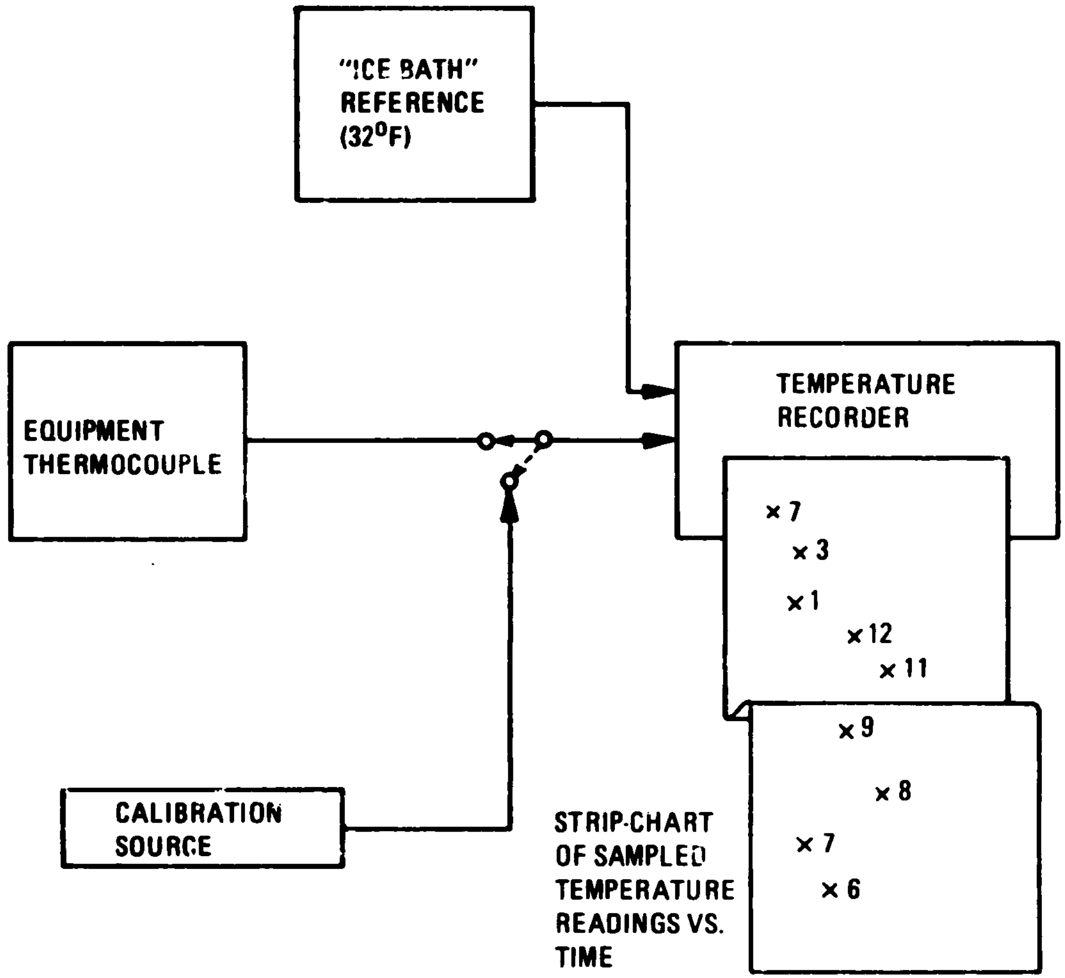


Figure A–8. Equipment Temperature Measurement

PARAMETER: CAR BODY VIBRATION
(Figure A-9)

Measurement Method/Concept

All car body vibrations are measured with linear servo accelerometers.

Sensors

1.	Type	Schaevitz Engineering Model LSB-2 accelerometer
2.	Quantity	11
3.	Range	±2.0 g
4.	Linearity	±0.05% full scale (best fit straight line)
5.	Hysteresis	±0.02% full scale
6.	Frequency response	0-20Hz
7.	Resolution	0.0005% full scale
8.	Calibration accuracy	0.1%

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Centrifuge
• Secondary	Voltage substitution

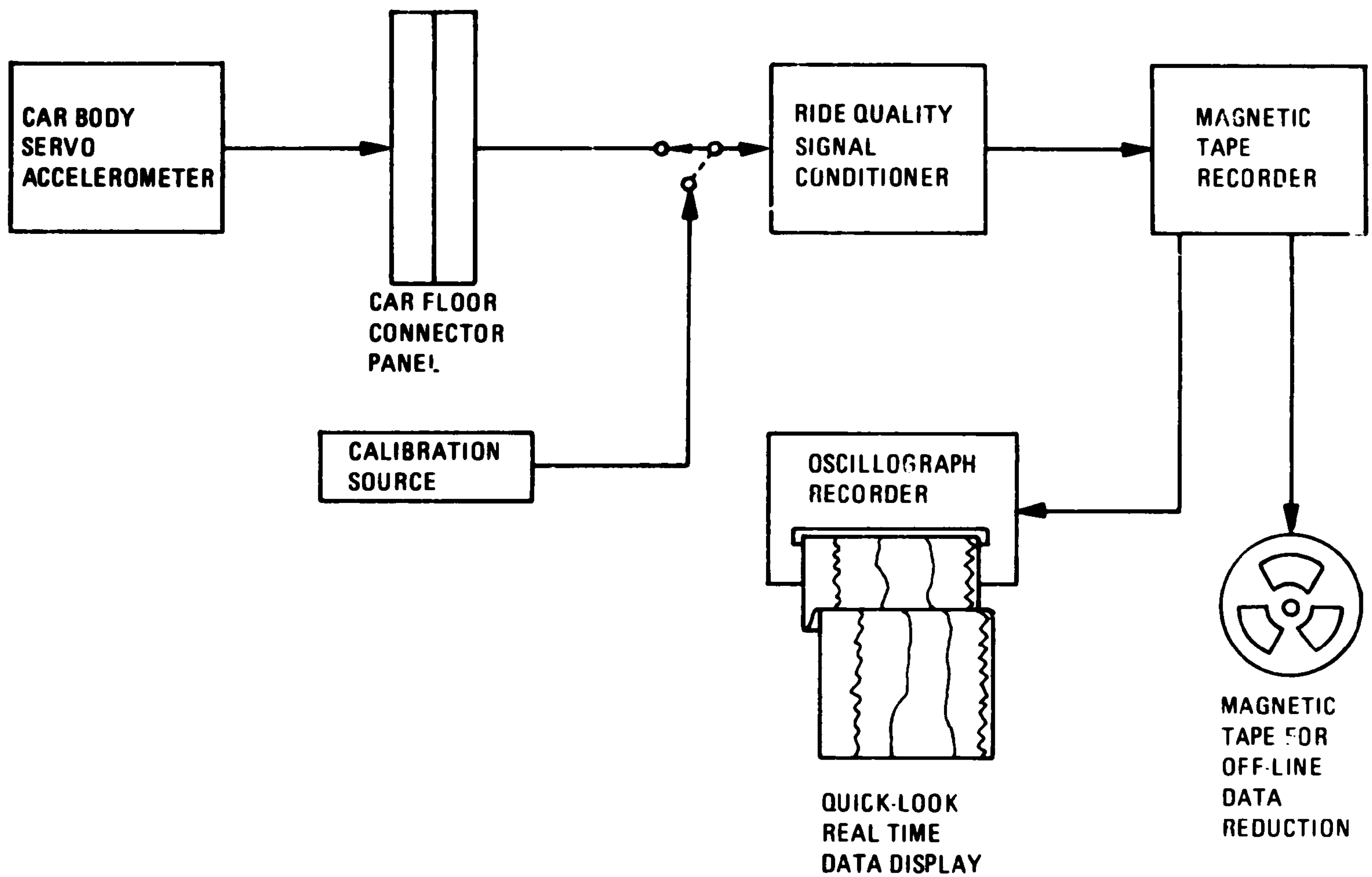


Figure A–9. Car Body Vibration Measurement

PARAMETER: TRUCK VIBRATION
(Figure A-10)

Measurement Method/Concept

All truck vibrations are measured with linear servo accelerometers.

Sensors

1.	Type	Schaevitz Engineering Model LSB-20 accelerometer
2.	Quantity	10
3.	Range	$\pm$20g
4.	Linearity	$\pm$0.05% full scale (best fit straight line)
5.	Hysteresis	$\pm$0.02% full scale
6.	Frequency response	0-30Hz
7.	Resolution	0.0005% full scale
8.	Calibration accuracy	0.1%

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy, 1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Centrifuge
• Secondary	Voltage substitution

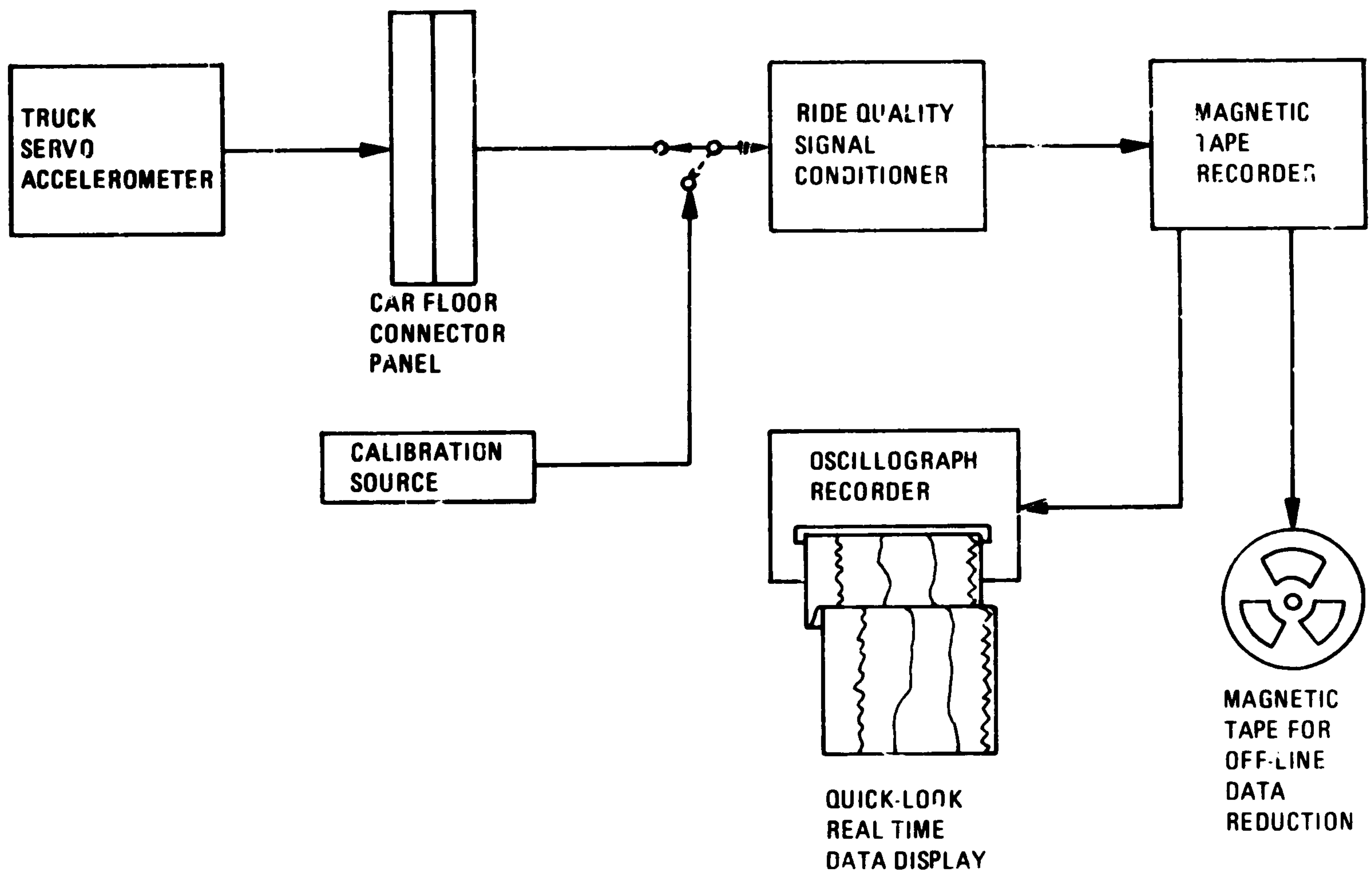


Figure A–10. Truck Vibration Measurement

PARAMETER: CAR BODY ANGULAR ACCELERATION (ROLL, PITCH, YAW) (Figure A-11)

Measurement Method/Concept

All angular accelerations will be measured with angular strain gage type accelerometers.

Sensors

1.	Type	Statham Model AA-17-300 accelerometer
2.	Quantity	3 (1 each for roll, pitch, yaw)
3.	Range	± 1.5 radians/second/second
4.	Non-linearity and Hysteresis	$< \pm 2.0\%$ full scale
5.	Frequency response	0-4 Hz

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, gain, offset and balance
- Overall accuracy, $\pm 1.0\%$

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Servo rate table and tachometer
• Secondary	Strain gage bridge unbalance using shunt resistance

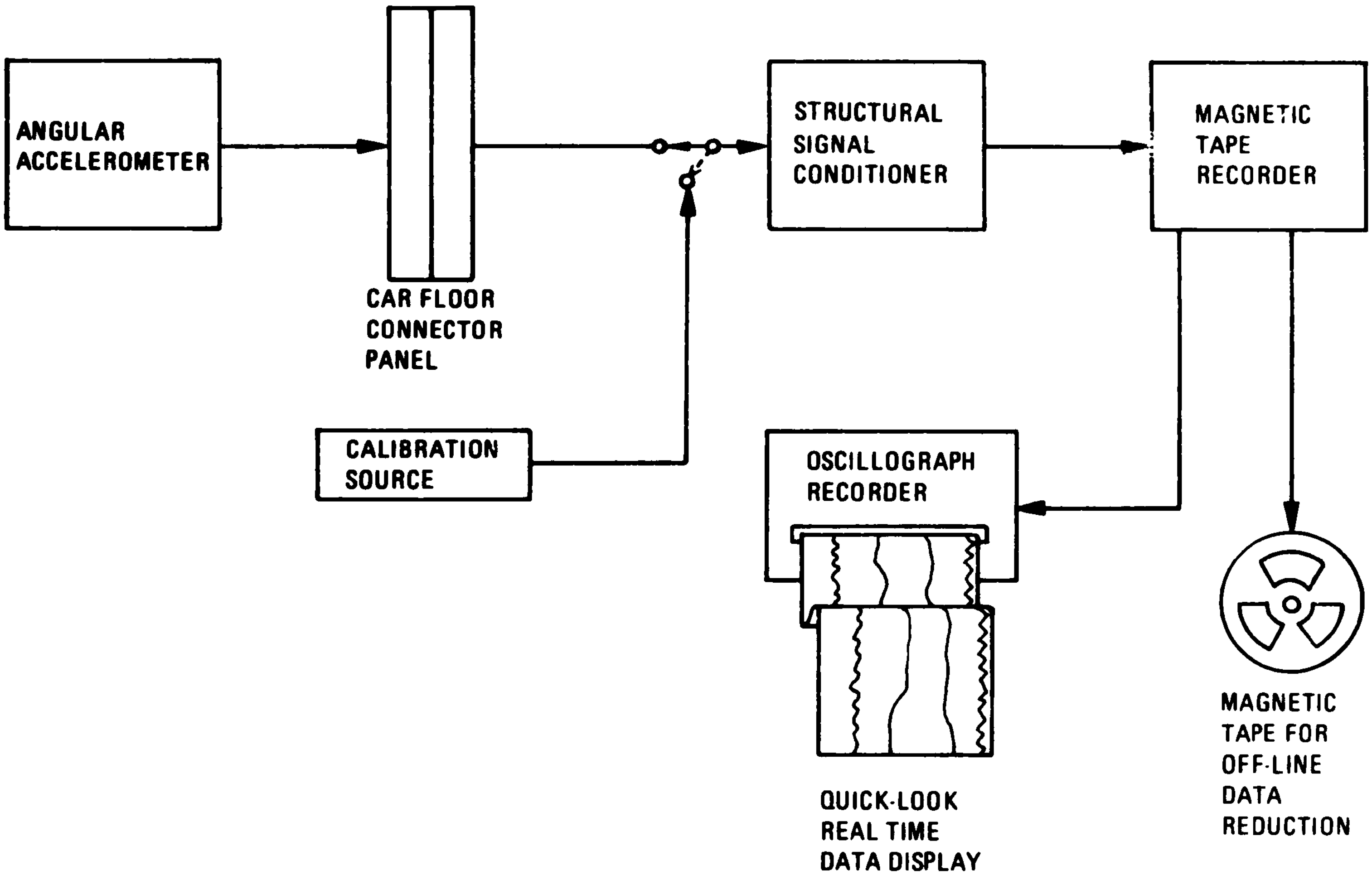


Figure A—11. Measurement of Car Body Angular Acceleration (Roll, Pitch and Yaw)

PARAMETER: AIRSPRING DISPLACEMENT, BOLSTER ANCHOR ROD DISPLACEMENT, CHEVRON DISPLACEMENT
(Figure A-12)

Measurement Method/Concept

All displacements are measured with linear potentiometric sensors.

Sensors

1. Type	Research Inc. Model 4046
2. Quantity	14
3. Range	0-0.5 inches (Bolster anchor rod)
	0-3.5 inches (Airspring, Chevron)
4. Resolution	0.007 inches

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, offset and balance
- Overall accuracy, $\pm1.0\%$

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Micrometer and gage blocks
• Secondary	Resistance substitution

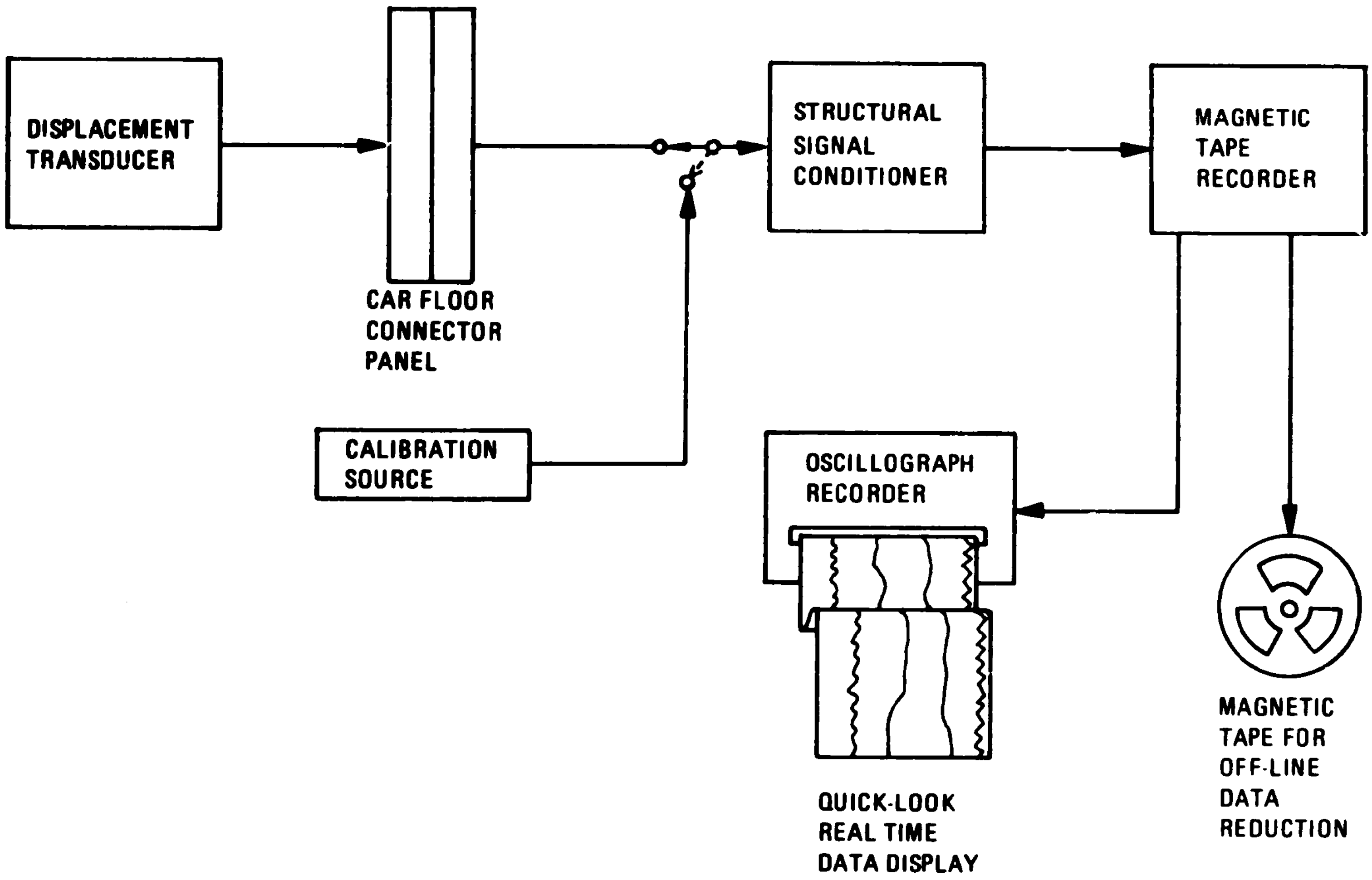


Figure A–12. Measurement of Airspring, Bolster Rod, and Chevron Displacement

PARAMETER: DAMPER LOAD
(Figure A-13)

Measurement Method/Concept

The damper rods are instrumented with semiconductor strain gages to measure axial strain as a result of alternating axial load.

Sensors

1.	Type	Semiconductor strain gage (full bridge)
2.	Quantity	16 (4 per damper rod)
3.	Range	±1500 lb. (calibrated at ±1000 lb.)
4.	Calibration	±1.0% full scale
5.	Frequency response	2 to 100 Hz

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, gain, offset and balance
- Overall accuracy, ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Tensile test machine
• Secondary	Strain gage bridge unbalance using shunt resistance

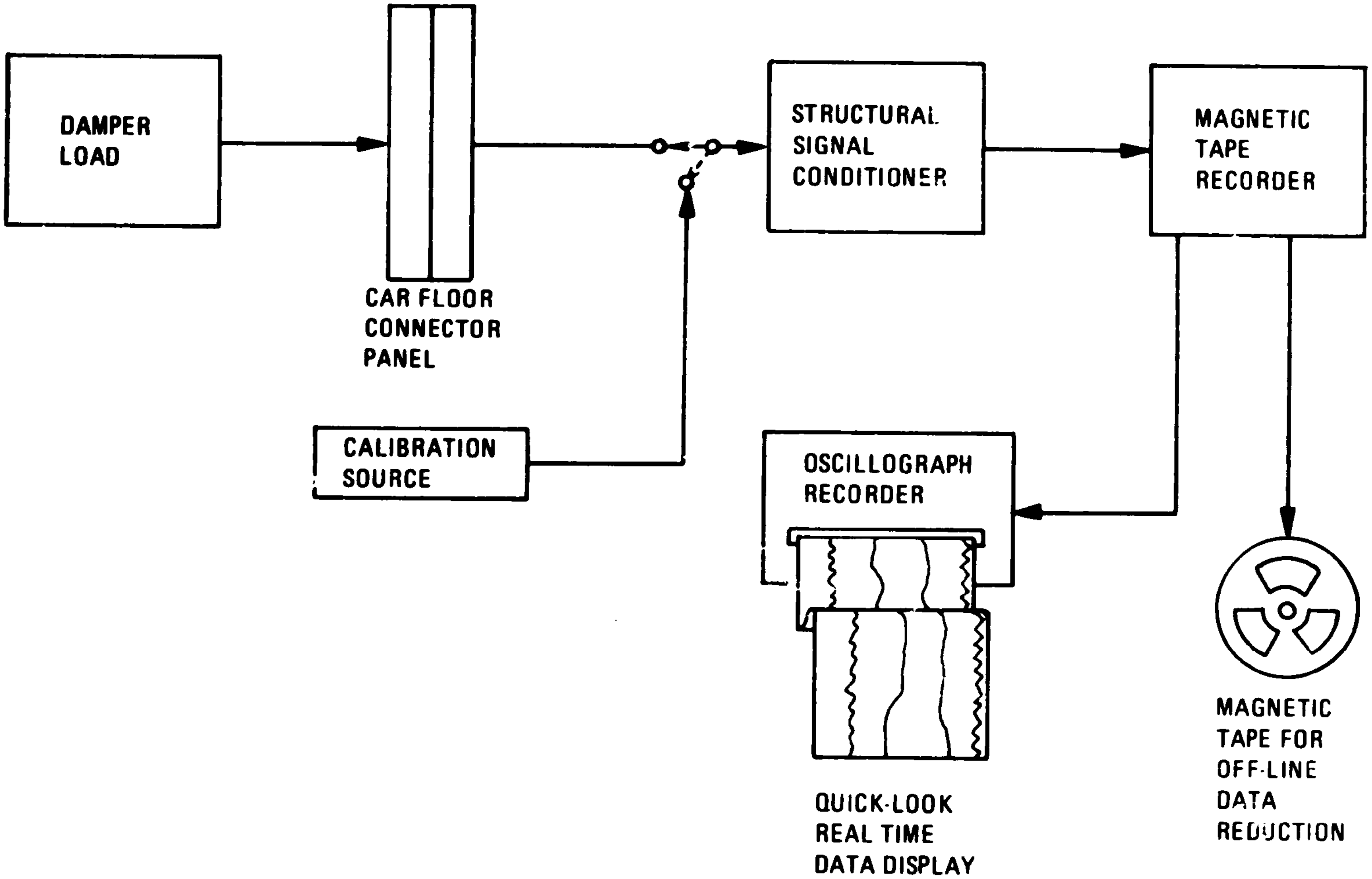


Figure A–13. Damper Rod Load Measurement

PARAMETER: TRUCK FRAME STRAIN GAGES
(Figure A-14)

Measurement Method/Concept

Strain gages are mounted on the truck frame to measure alternating strain.

Sensors

1.	Type	Wire type strain gage
2.	Quantity	2
3.	Range	0-10,000 psi
4.	Frequency response	2 to 100 Hz

Signal Conditioning

- AiResearch design
- Provides sensor power, buffering, gain, offset and balance
- Overall accuracy, ±1.0%

Recording Method

- Magnetic tape recorder
- Light beam oscillograph recorder

Calibration

• Primary	Strain gage bridge unbalance using shunt resistance
• Secondary	Same as primary

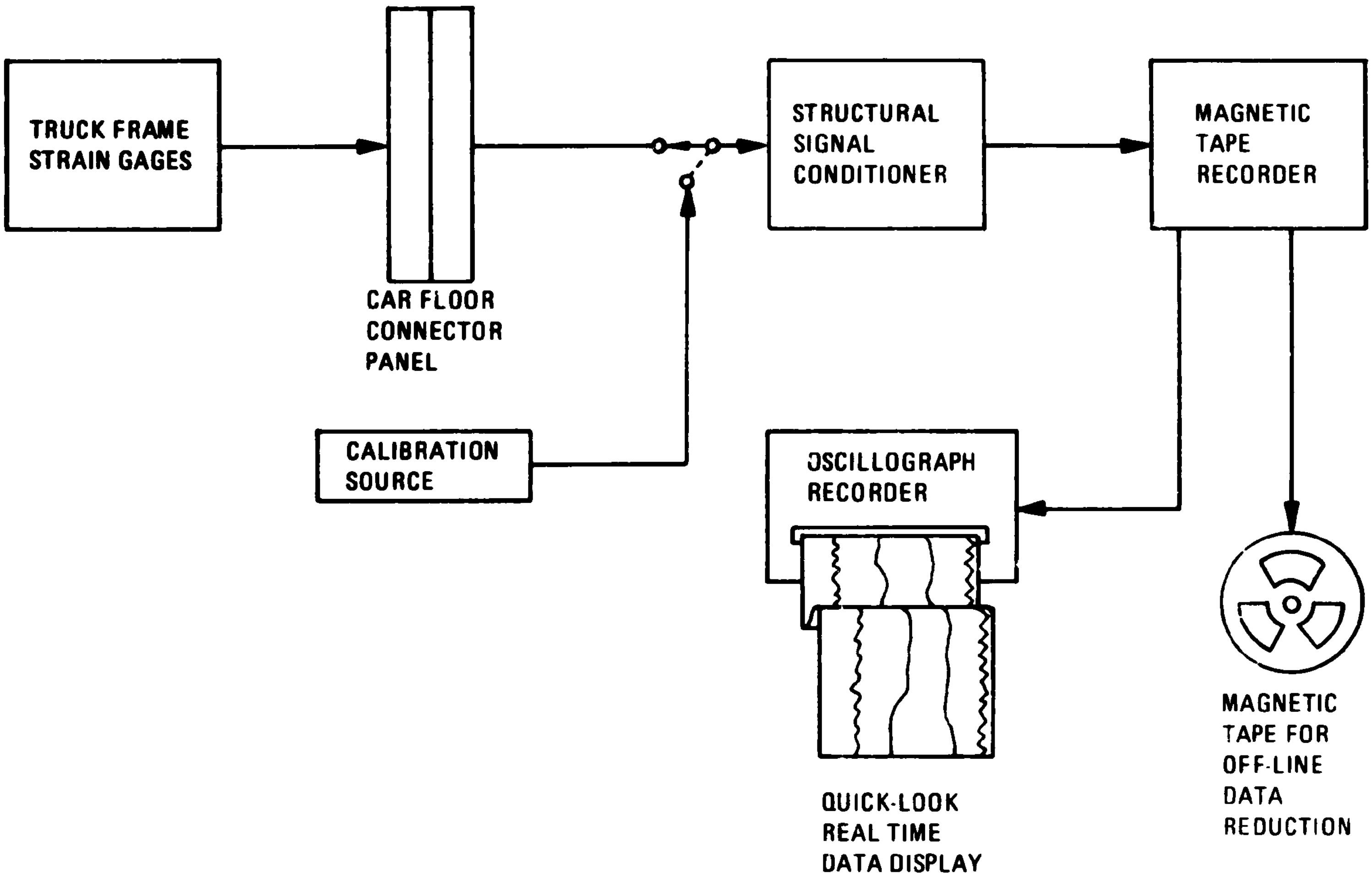


Figure A–14. Truck Frame Strain Measurement

Appendix B

SENSOR PHOTOGRAPHS

Figures B-1 through B-28 are photographs of the instrumentation and sensors, and their locations on the SOAC vehicle during engineering testing.

Figure B–1. Instrumentation System Cabinet

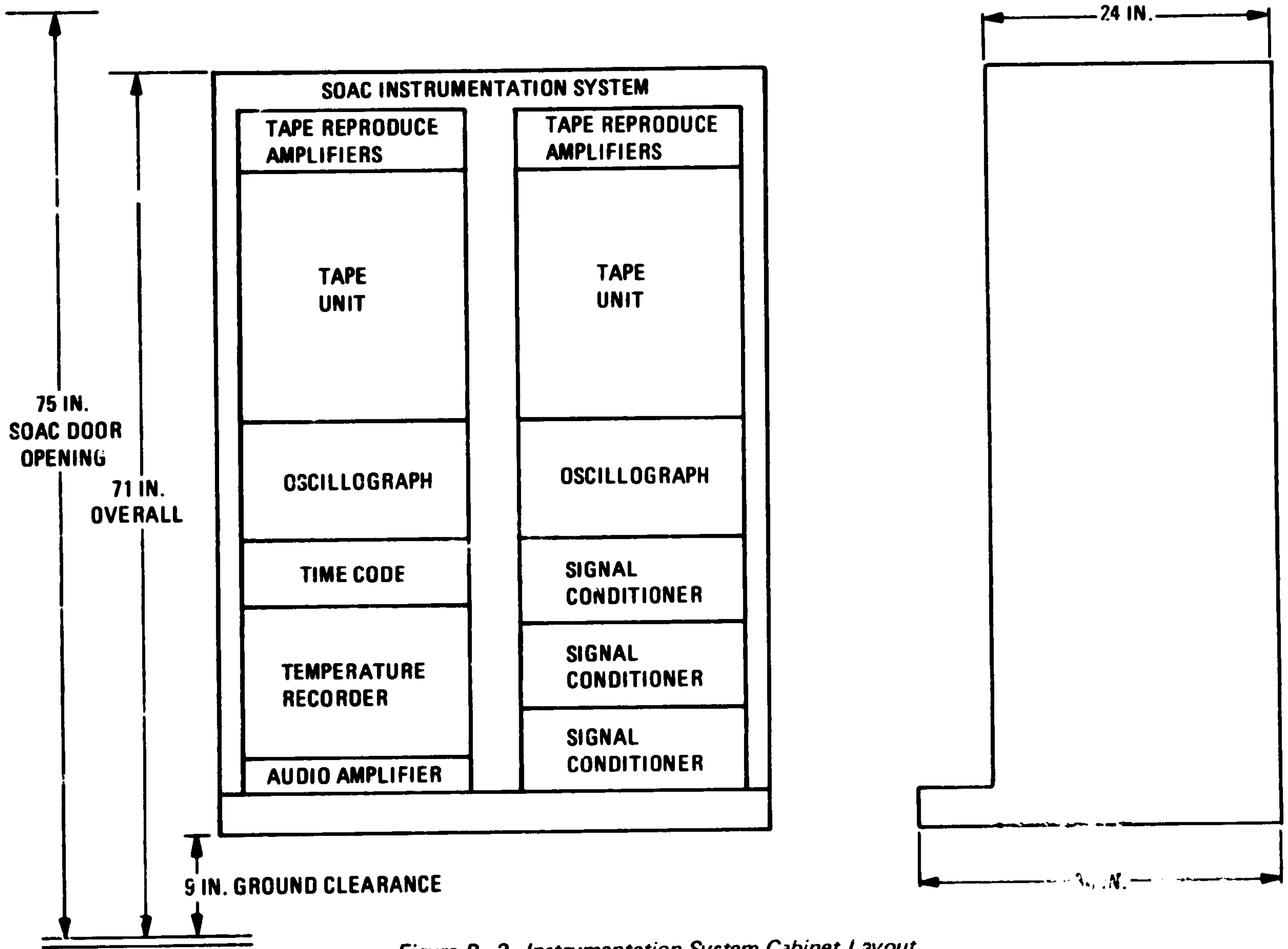


Figure B–2. Instrumentation System Cabinet Layout

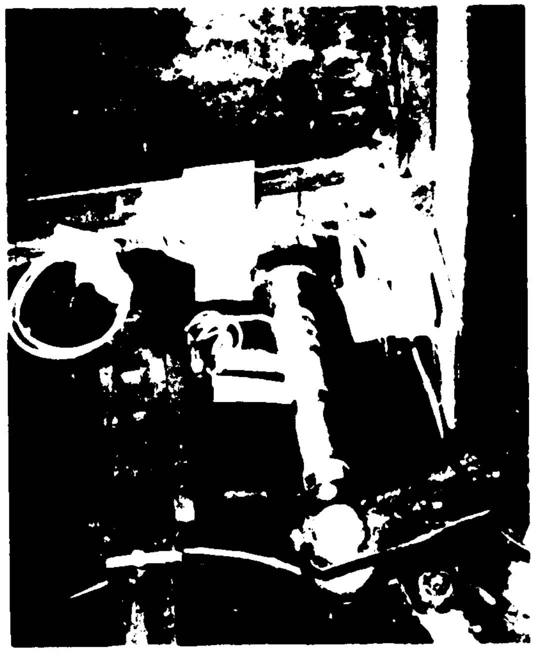


Figure B–3. Left-Hand Bolster-to-Car-Body Area Instrumentation: Vertical Damper Load; Vertical Airspring Displacement; Forward-Car-Floor/Truck-Center Vertical Accelerometer

Figure B–4. Vertical and Lateral Accelerometers at Rear End Car Floor Centerline

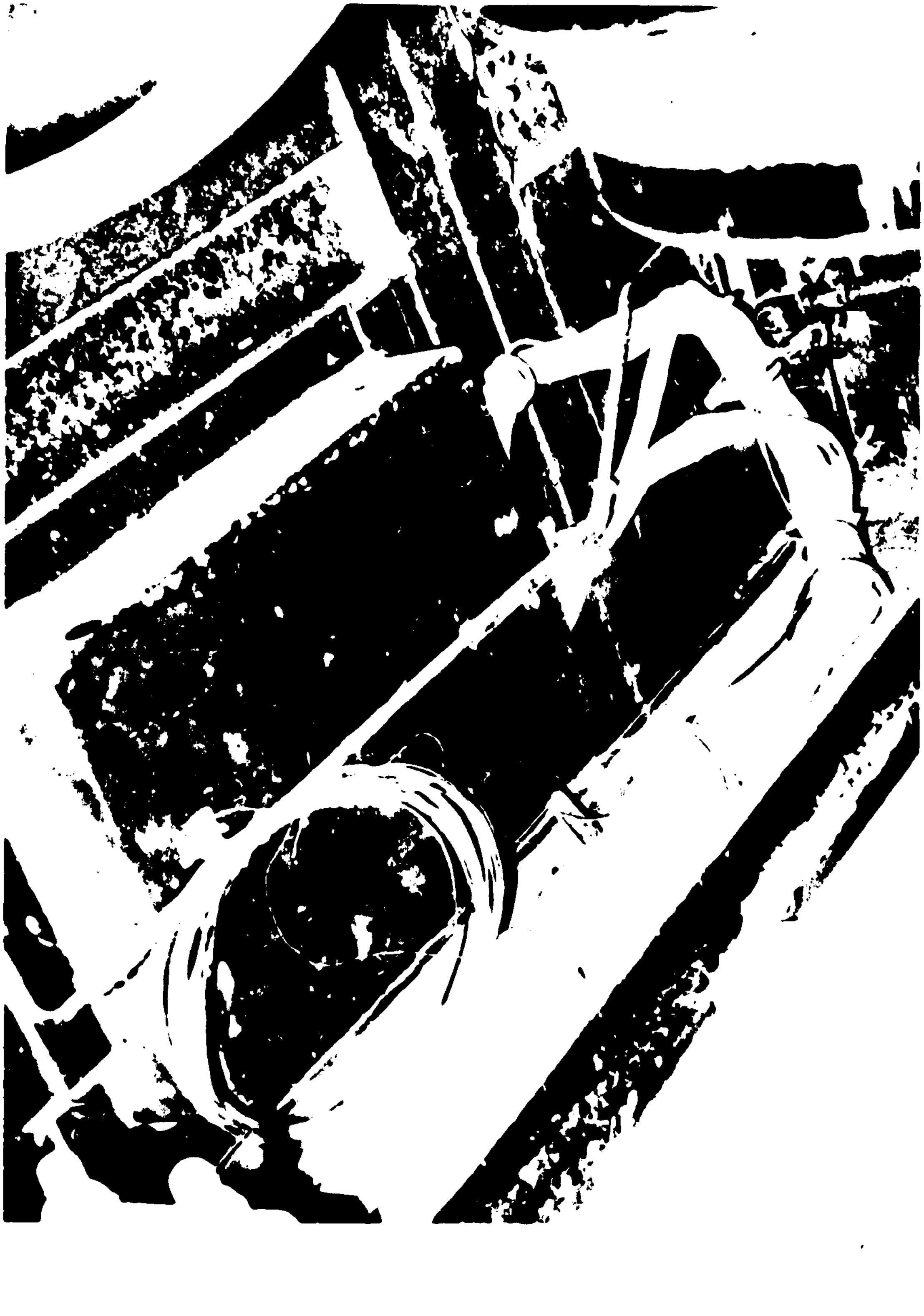


Figure B–5. View of Cabling Junction Box Beneath Car

Figure B–6. Interior View of Cabling Junction Box (Disassembled)

Figure B–7. Angular Accelerometers at Midcar Centerline

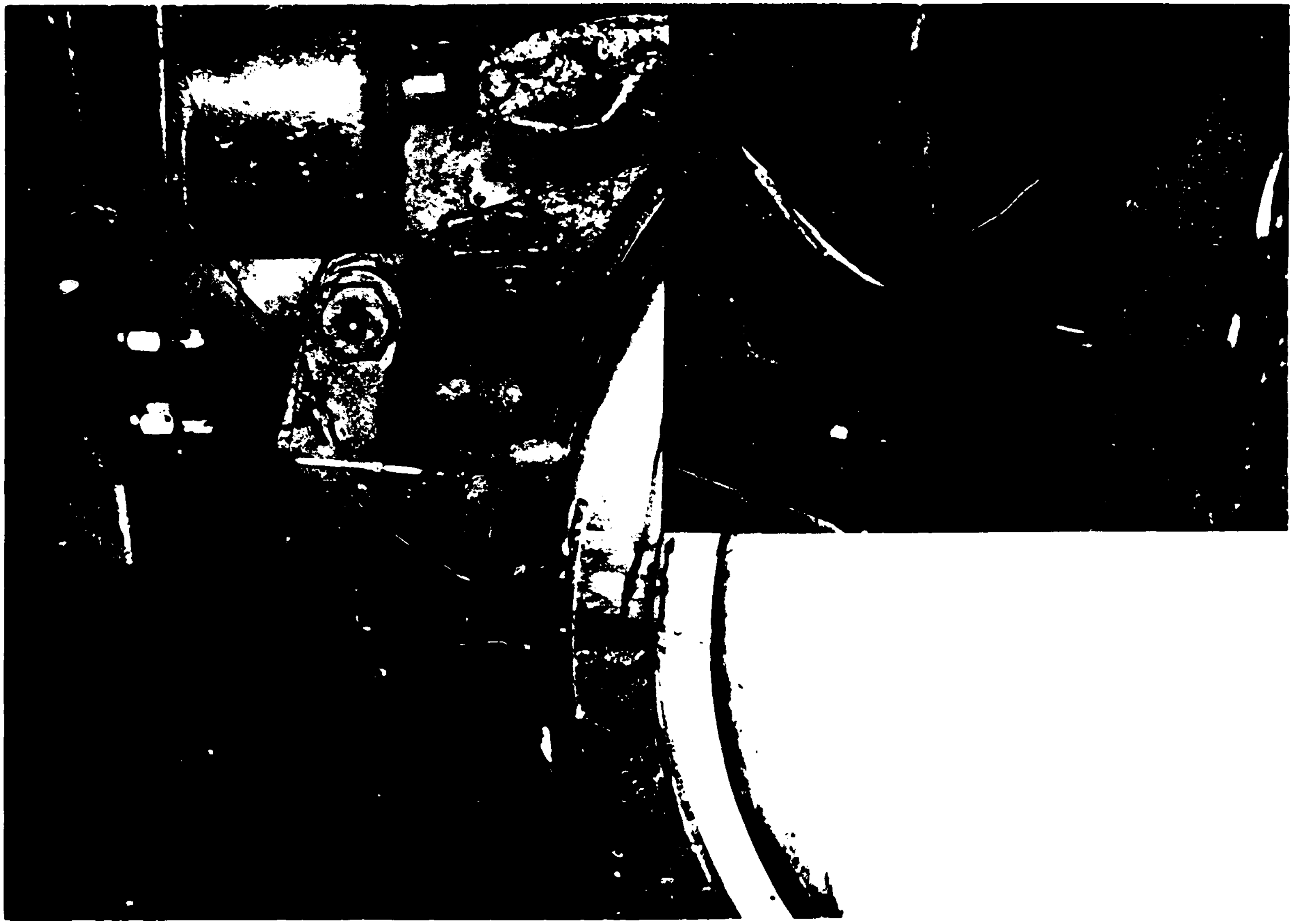


Figure B–8. Right-Hand Axle Brake Shoe Thermocouple

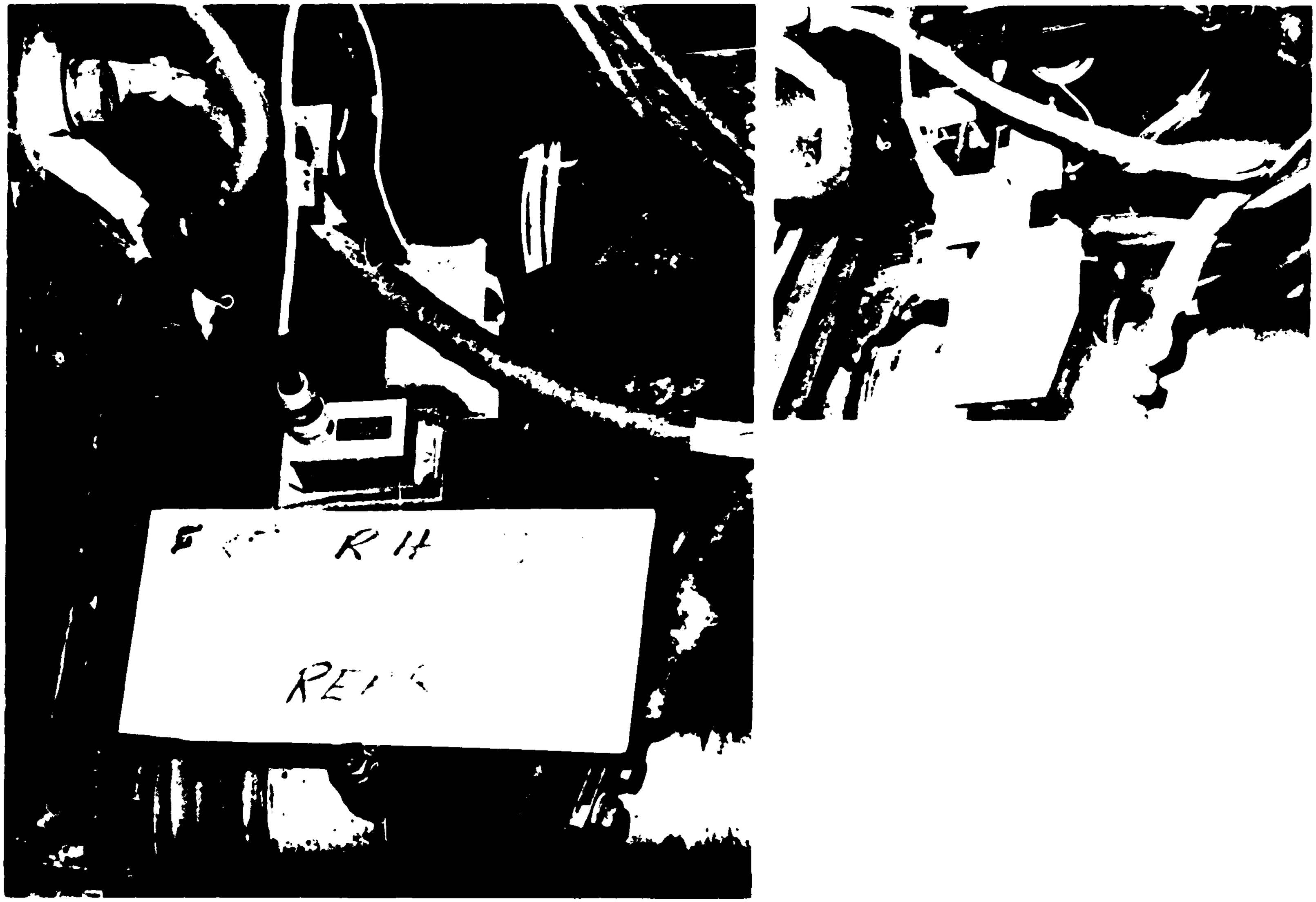


Figure B–9. Rear-Truck Forward-Axle Right-Hand-Wheel Area Instrumentation: Lateral Accelerometer; Vertical and Lateral Chevron Displacement

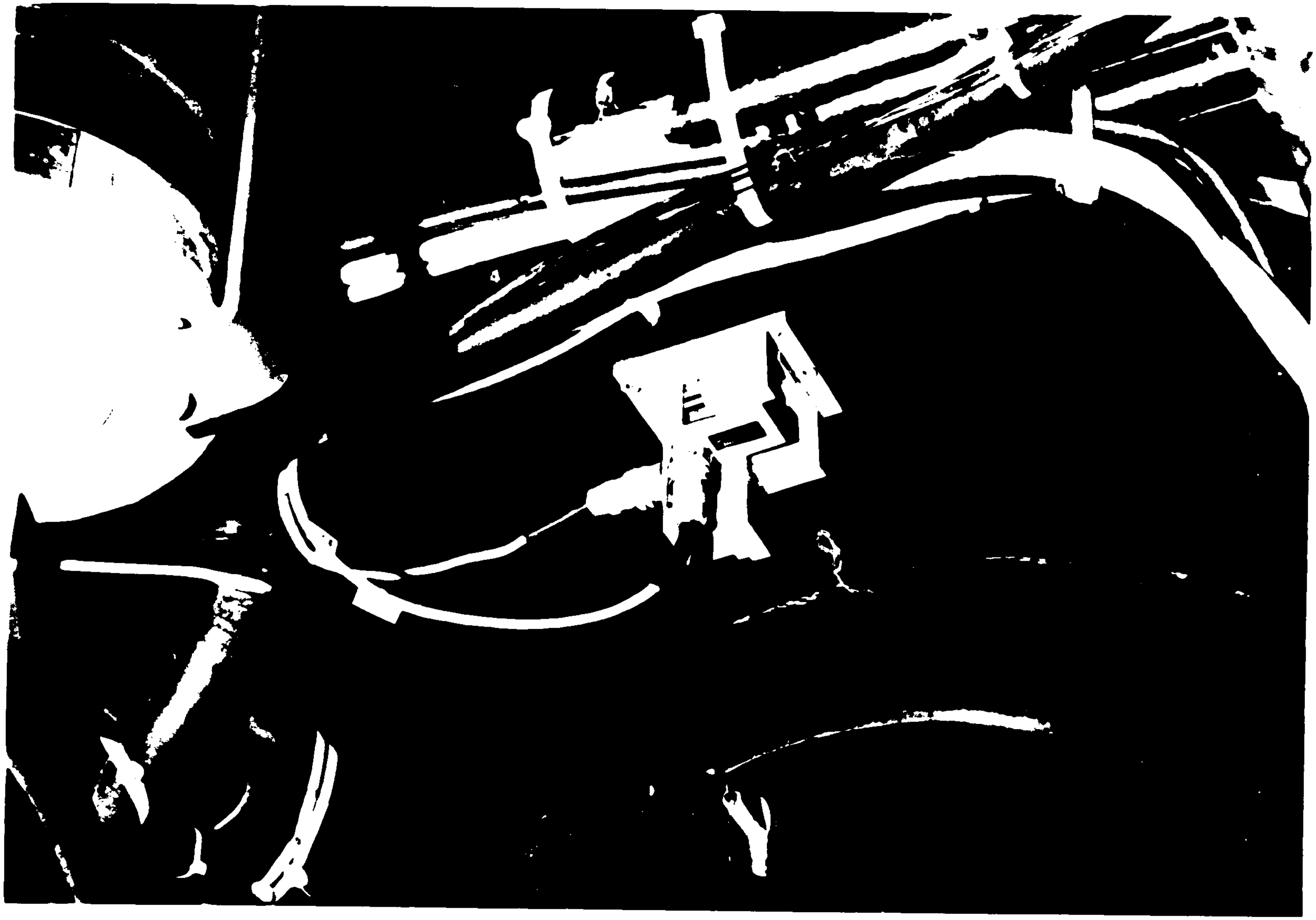


Figure B–10. Vertical and Lateral Accelerometers Beneath Midcar Floor Centerline

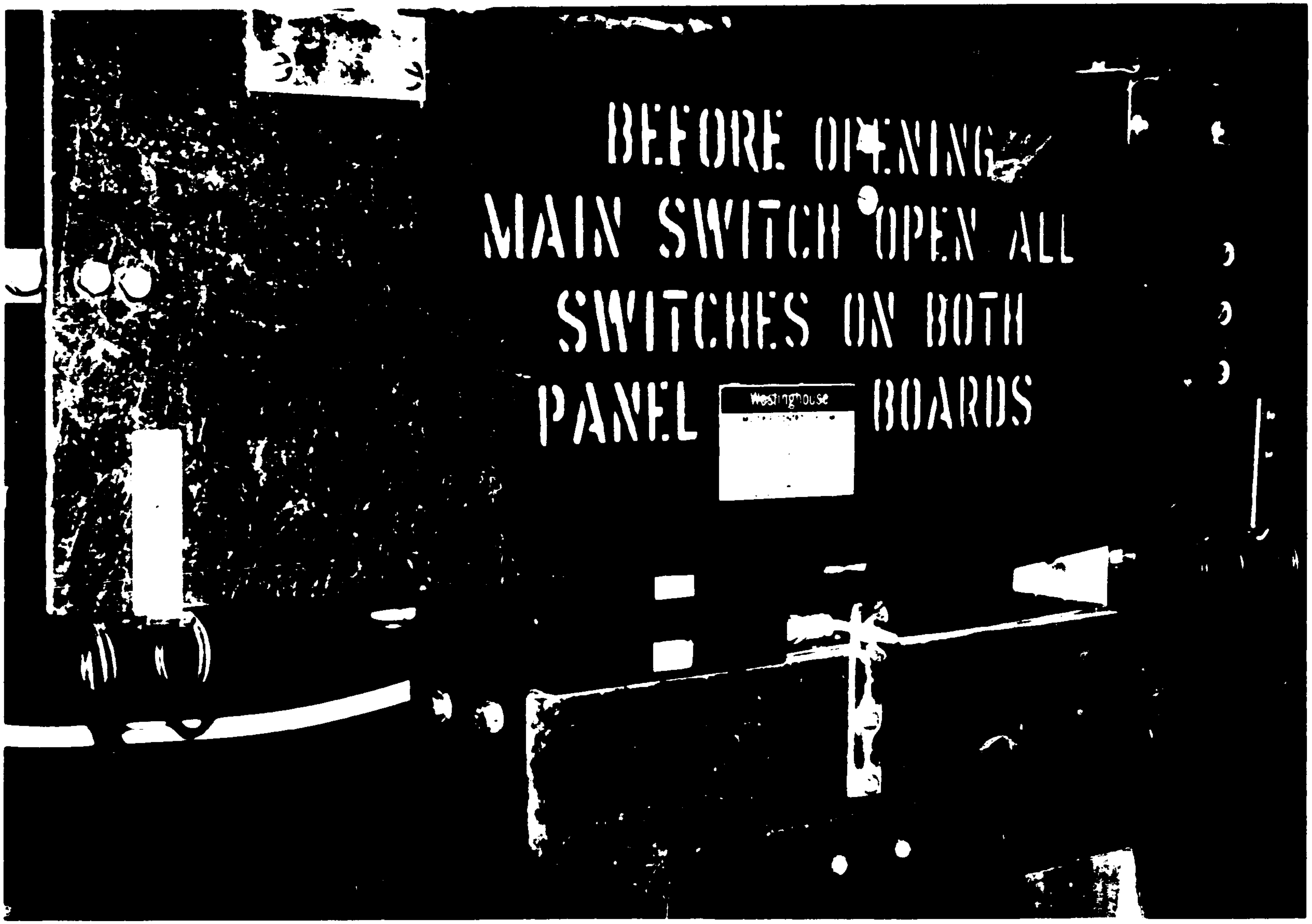


Figure B—11. Line Current Fuse and Main Switch

Figure B–12. Vertical Accelerometer Beneath Left-Hand Midcar Floor

Figure B–13. Front-Truck Aft-Axle Left-Hand-Wheel Area Instrumentation: Vertical Accelerometer; Vertical Chevron Displacement

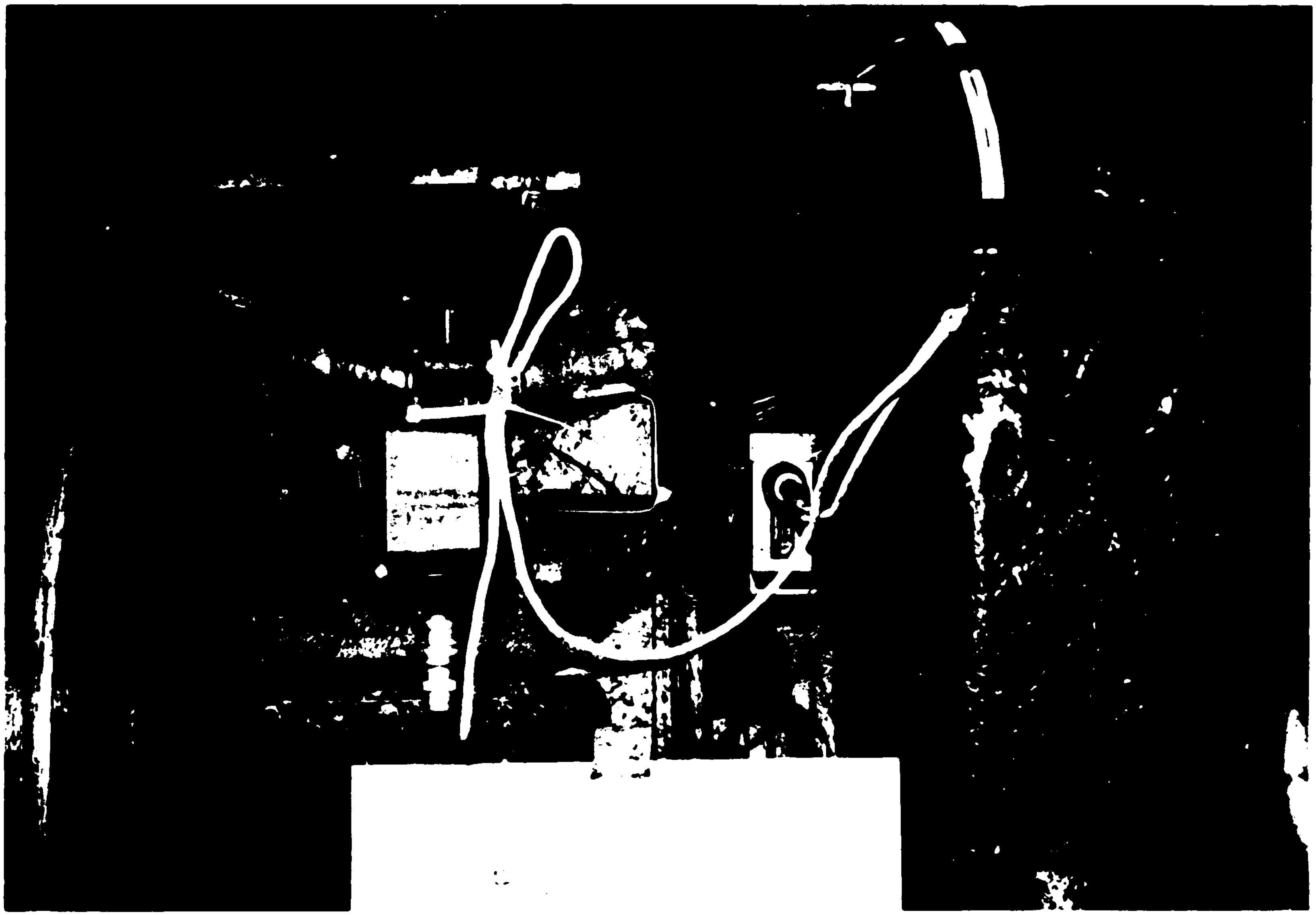


Figure B–14. Front-Truck Forward-Axle Left-Hand-Wheel Area Instrumentation: Vertical Accelerometer; No. 1 Armature Current Sensor.

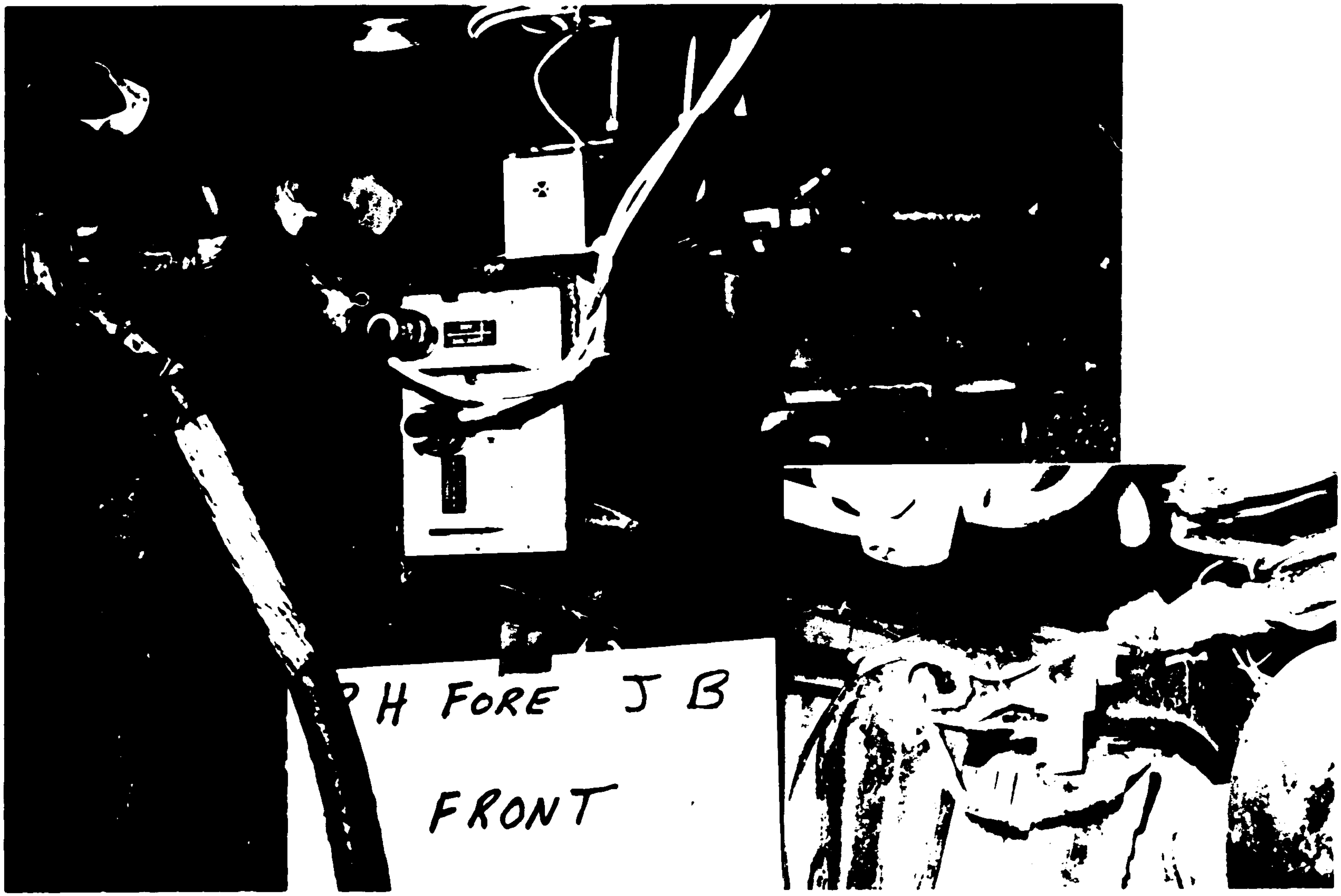


Figure B–15. Front-Truck Forward-Axle Right-Hand-Wheel Area Instrumentation: Vertical and Lateral Accelerometers; Vertical and Lateral Chevron Displacement

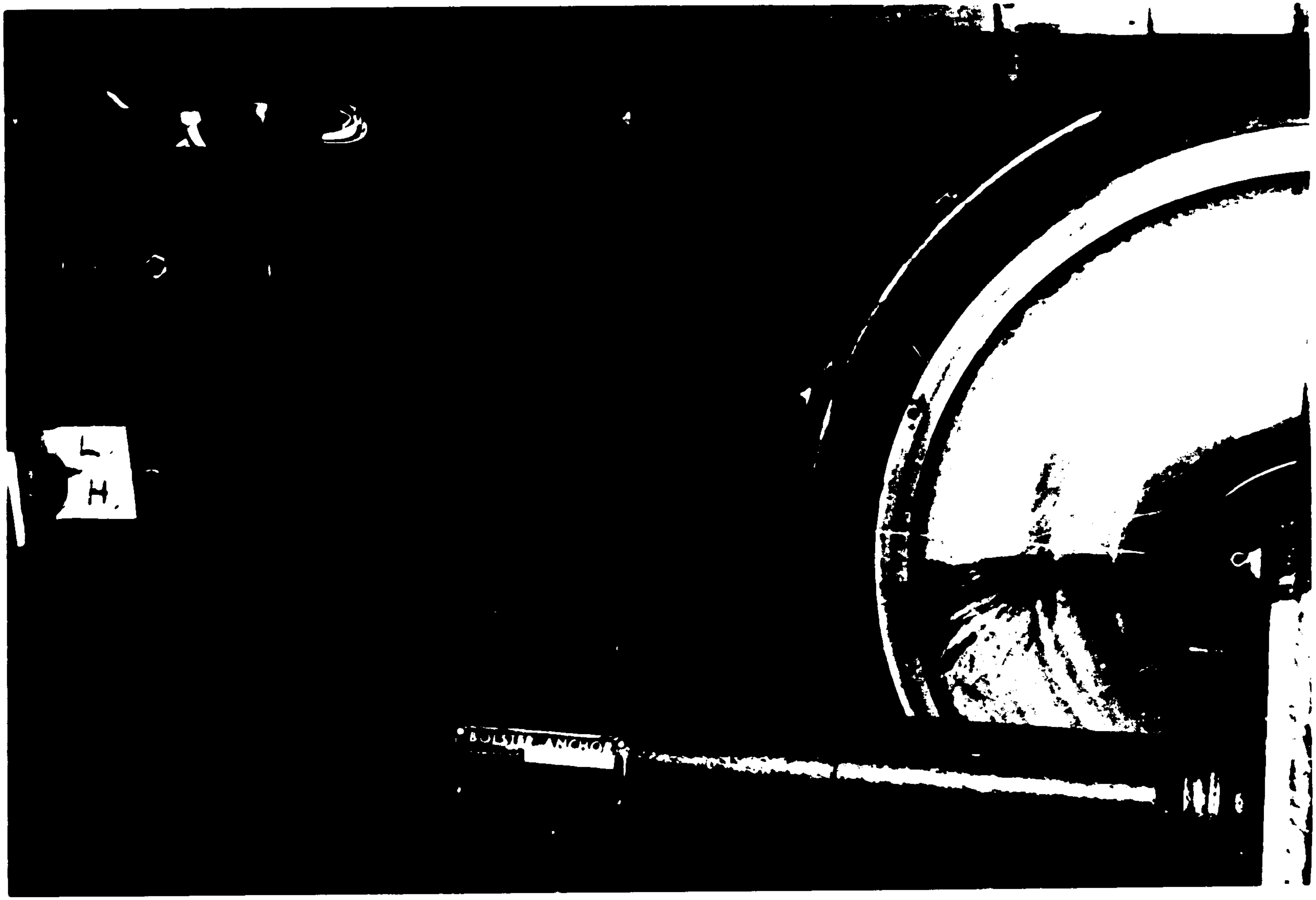


Figure B–16. Instrumentation for Measuring Left-Hand Bolster Lateral Displacement

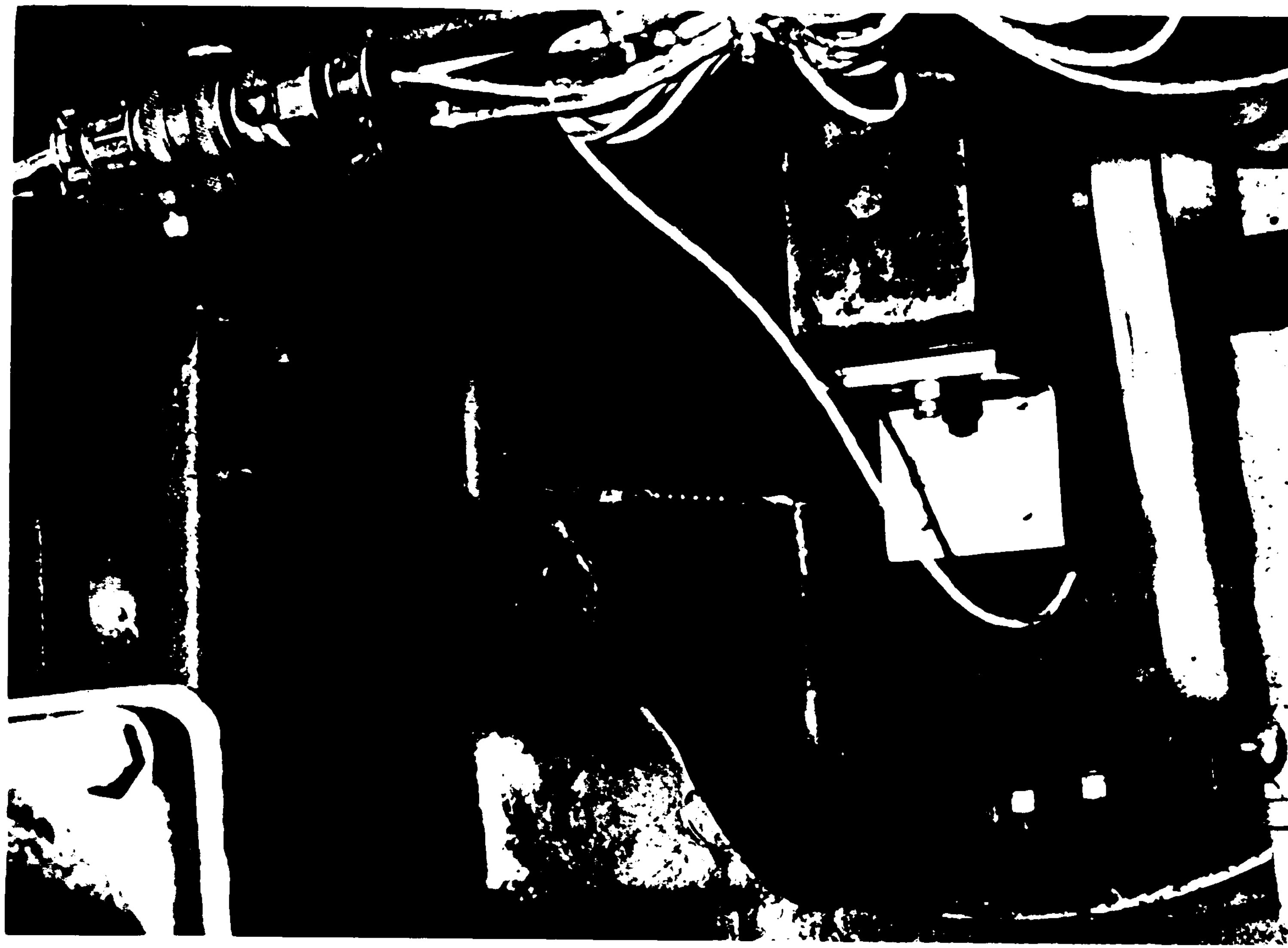


Figure B–17. Instrumentation for Measuring Left-Hand Airspring Lateral Displacement

Figure B–18. Vertical, Lateral and Longitudinal Accelerometers at Forward-Car-Body Car-Floor Truck-Centerline Area

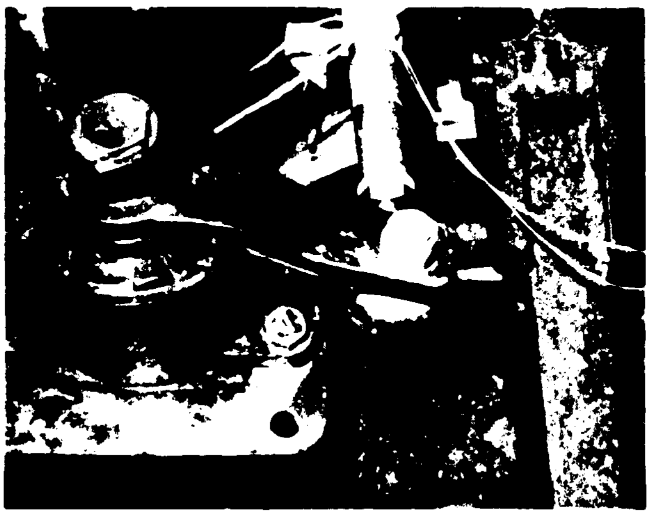


Figure B–19. Instrumentation for Measuring Right-Hand Vertical Airspring Displacement and Right-Hand Vertical Damper Load

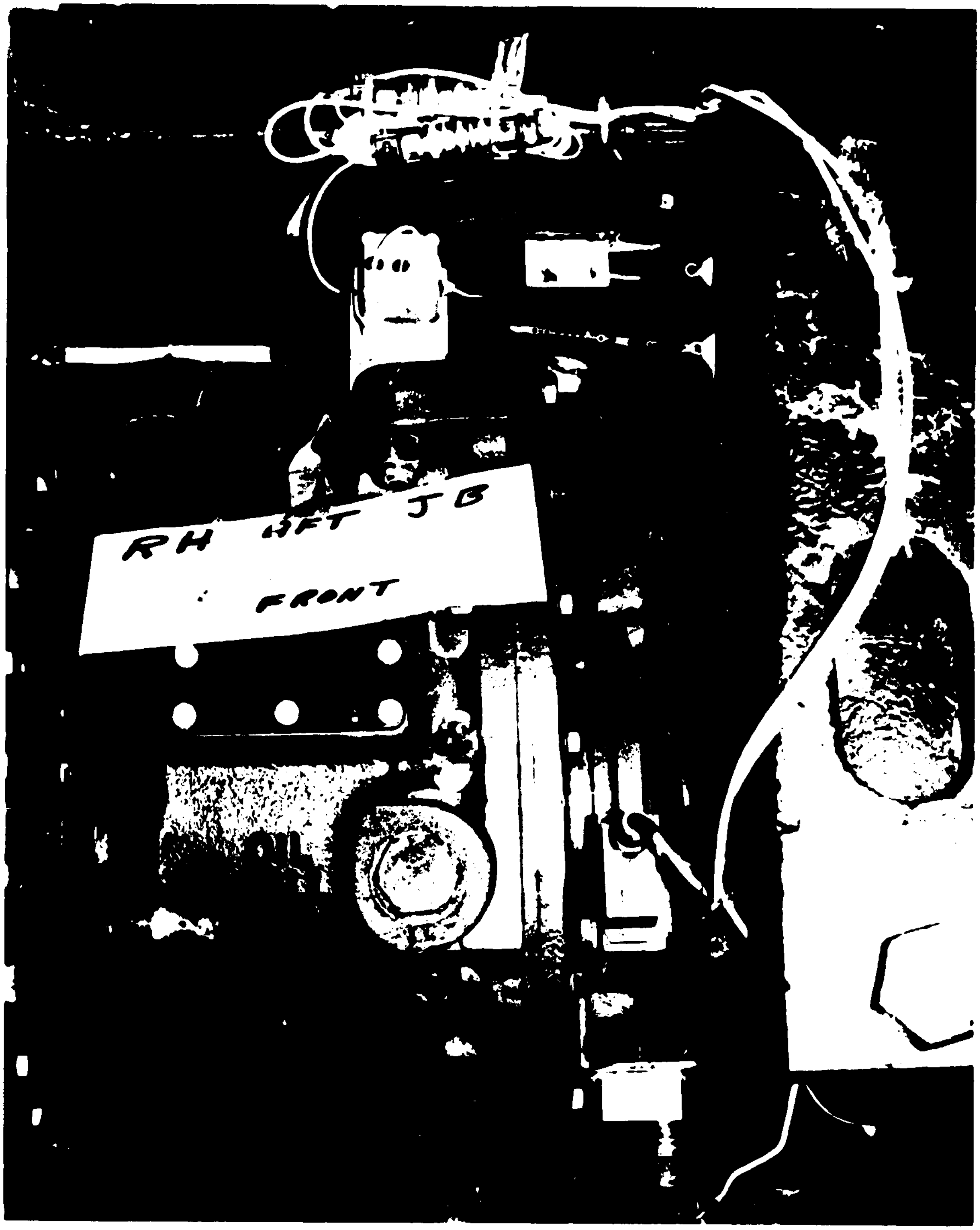


Figure B–20. Front-Truck Aft-Axle Right-Hand-Wheel Area Instrumentation: Vertical and Lateral Accelerometers; Vertical and Lateral Chevron Displacement

Figure B–21. Instrumentation for Measuring Right-Hand Bolster Anchor Rod Displacement

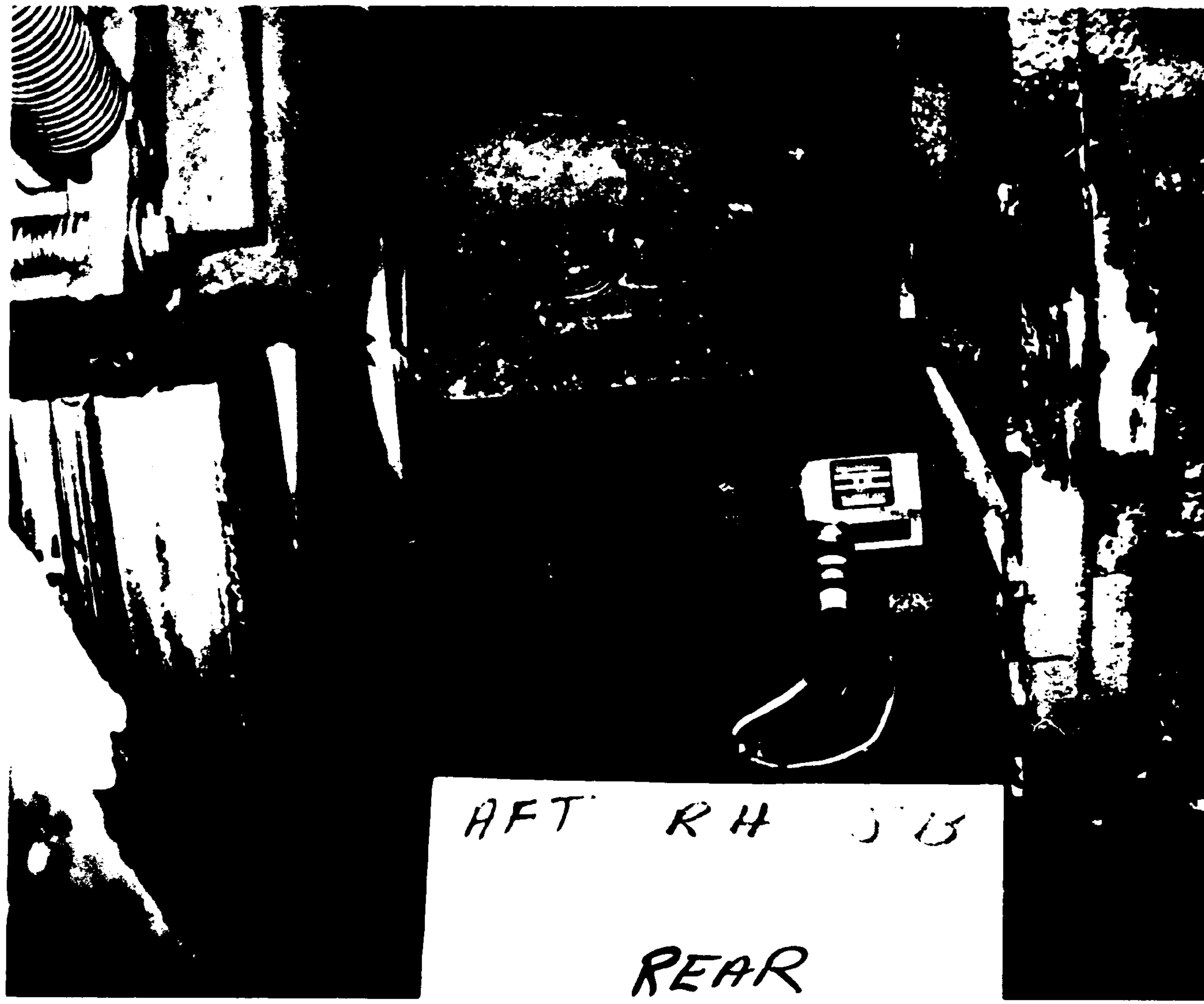


Figure B–22. Lateral Accelerometer at Rear-Truck Aft-Axle Right-Hand-Wheel Area.

Figure B–23. Vertical and Lateral Accelerometers at Centerline of Forward Motor Housing

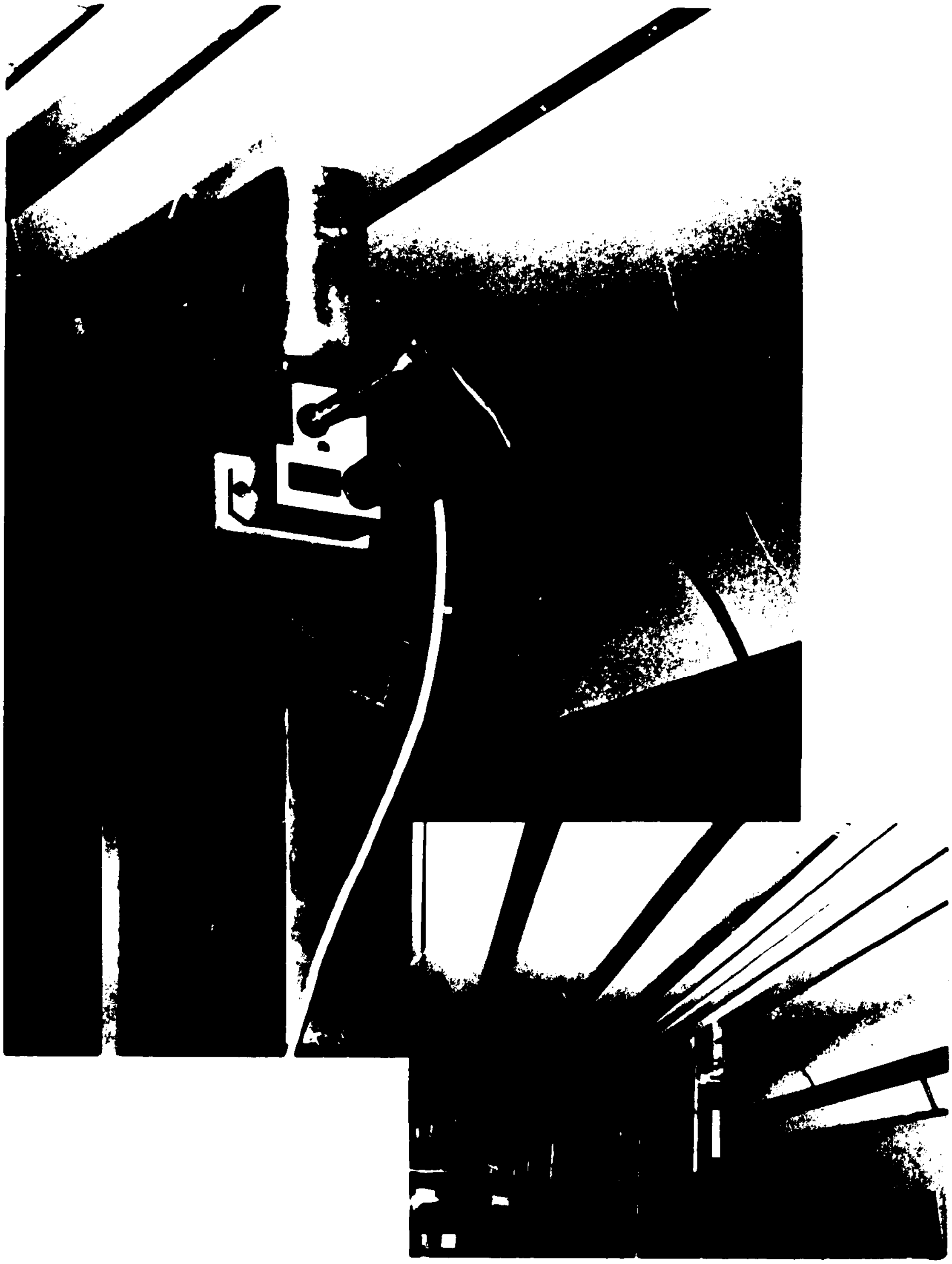


Figure B–24. Lateral Accelerometer at Midcar Ceiling Centerline

Figure B–25. Power Inverter

Figure B–26. Vertical Accelerometer at Midcar Floor on Right-Hand Side

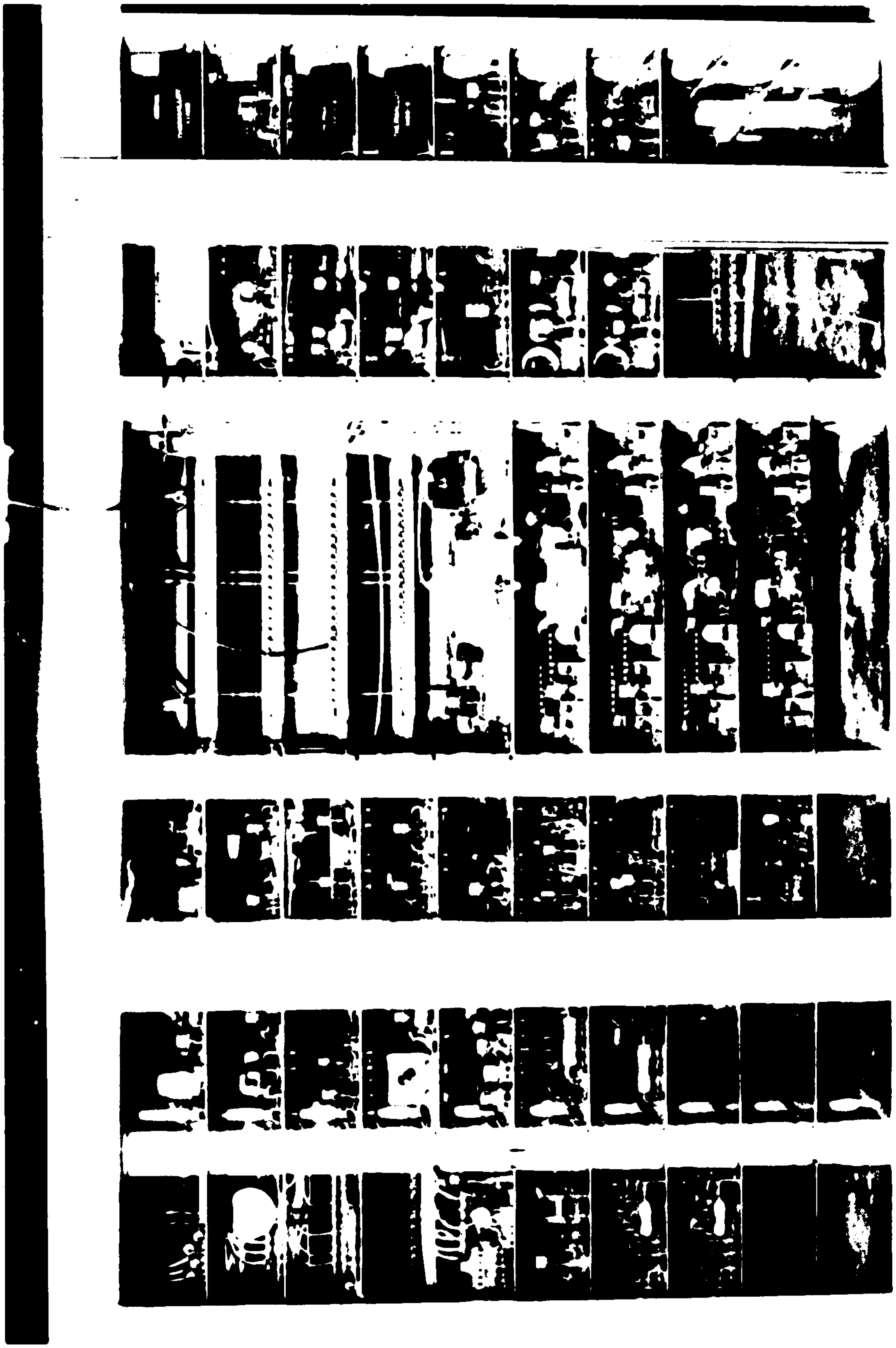


Figure B–27. Free-Air Thermocouple at Propulsion Power Unit

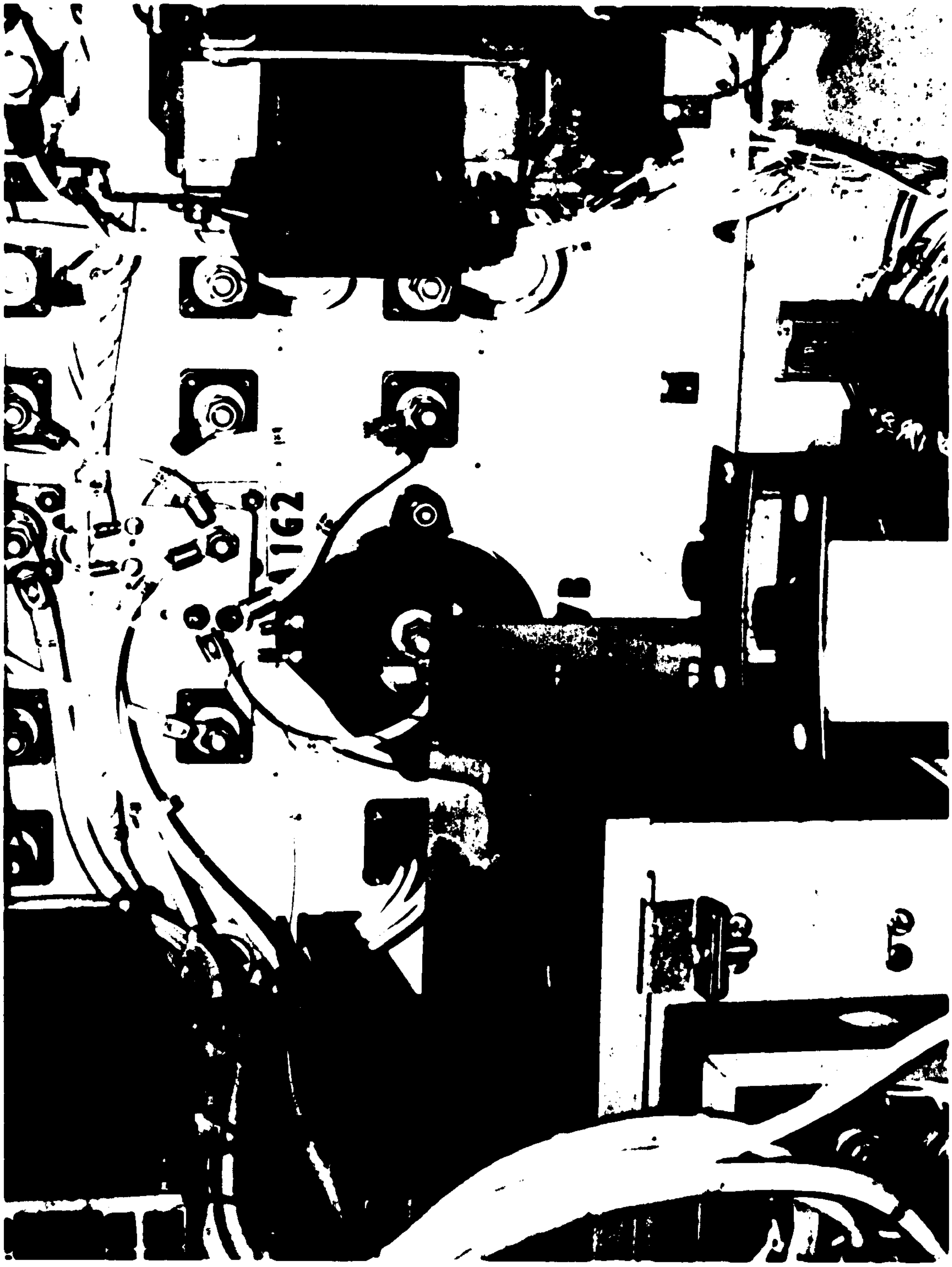


Figure B–28. Free-Air Thermocouple at Auxiliary Power Control Unit